TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF MINING, Metallurgical, and Petroleum ENGINEERS.

VOL. XXXI.

CONTAINING THE PAPERS AND DISCUSSIONS OF 1901, EXCEPT THOSE WHICH RELATE TO THE MINERAL RESOURCES AND INDUSTRIES OF MEXICO, WHICH WILL BE PUBLISHED IN VOL. XXXII.

NEW YORK CITY:
PUBLISHED BY THE INSTITUTE,
AT THE OFFICE OF THE SECRETARY.
1902.

PREFACE.

As explained on the title-page, this volume contains the papers of 1901 (*i.e.*, those presented at the Richmond meeting in February and at the Mexican meeting in November) except such as deal, more or less directly, with the resources and industries of Mexico. When it was found necessary, by reason of the overwhelming amount of material furnished and accepted for the *Transactions* during the year, to issue two volumes instead of one, the division of this material in such a way that Vol. xxxii. should include the specially Mexican part of it, was obviously suggested. That volume is now in press, and will be issued as soon as practicable after the appearance of this one. It will contain the Proceedings of the Mexican meeting, and the illustrated account of the Excursions and Entertainments connected therewith, as well as the appropriate papers.

The foregoing statement will explain the presence, in this volume, of papers presented at the Mexican meeting, but not treating of Mexican subjects.

R. W. RAYMOND.

CONTENTS.

DISCUSSIONS.

OFFICERS.

For year ending February, 1902.*

President.

EBEN E. OLCOTT, New York City.

Vice-Presidents.

DAVID T. DAY........Washington, D. C.
J. B. RANDOL........New York City.
W. C. RALSTON........San Francisco, Cal.

(Term expires February, 1902.)

CARLOS F. DE LANDERO........Pachuca, Mexico.
JOHN E. HARDMAN........Montreal, Canada.
JOHN HAYS HAMMOND........Denver, Colo.

(Term expires February, 1903.)

Managers.

ARTHUR WINSLOW........Kansas City, Mo.
WILLIAM GLENN........Baltimore, Md.
W. J. TAYLOR........Bound Brook, N. J.

(Term expires February, 1902.)

D. H. BACON........Soudan, Minn.
E. V. D'INVILLIERS........Philadelphia, Pa.
WILLIAM KENT........Passaic, N. J.

(Term expires February, 1903.)

GEORGE A. CROCKER........New York City.
HORACE V. WINCHELL........Butte, Mont.
CLEMENS C. JONES........Richmond, Va.

(Term expires February, 1904.)

Secretary.

R. W. RAYMOND,
99 John St., New York City.

Treasurer.

THEODORE D. RAND,
Philadelphia, Pa.

Honorary Members.†

PROF. RICHARD ÅKERMAN........Stockholm, Sweden.
SIR LOWTHIAN BELL........Middlesborough, England.
DR. THOMAS M. DROWN........South Bethlehem, Pa.
PROF. HATON DE LA GOUPILLIÈRE........Paris, France.
PROF. HANS HOEFER........Leoben, Austria.
PROF. DR. BRUNO KERL........Berlin, Germany.
PROF. J. P. LESLEY........Philadelphia, Pa.
M. FLORIS OSMOND........Paris, France.
SIR WILLIAM C. ROBERTS-AUSTEN........London, England.
PROF. DR. HERMANN WEDDING........Berlin, Germany.
‡PROF. DIMITRY CONSTANTIN TSCHERNOFF........St. Petersburg, Russia.

---

* The following officers were elected at the Annual Meeting, February, 1901: *President*, E. E. Olcott, N. Y. City; *Vice-Presidents* (to serve two years), S. F. Emmons, Washington, D. C.; James Gayley, Pittsburg, Pa.; J. Henry Lee, Carbon Hill, Ala.; *Managers* (to serve three years), E. W. Parker, N. Y. City; James W. Neill, Salt Lake City, Utah; M. D. Valentine, Woodbridge, N. J.; *Treasurer*, Theodore D. Rand, Philadelphia, Pa.; *Secretary*, R. W. Raymond, N. Y. City.

† Hon. Manuel Maria Contreras, elected Honorary Member in 1902, died before receiving notice of his election.

‡ Elected April, 1902.

LIST OF THE MEETINGS OF THE INSTITUTE AND THEIR LOCALITIES FROM ITS ORGANIZATION TO MAY, 1902.

Number.	Place.	Date.	Transactions. Vol.	Page
I.	Wilkes-Barre, Pa.*	May, 1871	i.	3
II.	Bethlehem, Pa.	August, 1871	i.	10
III.	Troy, N. Y.	November, 1871	i.	13
IV.	Philadelphia, Pa.	February, 1872	i.	17
V.	New York, N. Y.*	May, 1872	i.	20
VI.	Pittsburg, Pa.	October, 1872	i.	25
VII.	Boston, Mass.	February, 1873	i.	28
VIII.	Philadelphia, Pa.*	May, 1873	ii.	3
IX.	Easton, Pa.	October, 1873	ii.	7
X.	New York, N. Y.	February, 1874	ii.	11
XI.	St. Louis, Mo.*	May, 1874	iii.	3
XII.	Hazleton, Pa.	October, 1874	iii.	8
XIII.	New Haven, Conn	February, 1875	iii.	15
XIV.	Dover, N. J.*	May, 1875	iv.	3
XV.	Cleveland, O.	October, 1875	iv.	9
XVI.	Washington, D. C.	February, 1876	iv.	18
XVII.	Philadelphia, Pa.†	June, 1876,	v.	3
XVIII.	Philadelphia, Pa.	October, 1876	v.	19
XIX.	New York, N. Y.	February, 1877	v.	27
XX.	Wilkes-Barre, Pa.*	May, 1877	vi.	3
XXI.	Amenia, N. Y.	October, 1877	vi.	10
XXII.	Philadelphia, Pa.	February, 1878	vi.	18
XXIII.	Chattanooga, Tenn.*	May, 1878,	vii.	3
XXIV.	Lake George, N. Y.	October, 1878	vii.	103
XXV.	Baltimore, Md.*	February, 1879	vii.	217
XXVI.	Pittsburg, Pa.	May, 1879	viii.	3
XXVII.	Montreal, Canada	September, 1879	viii.	121
XXVIII.	New York, N. Y.*	February, 1880	viii.	275
XXIX.	Lake Superior, Mich.,	August, 1880	ix.	1
XXX.	Philadelphia, Pa.,*	February, 1881	ix.	275
XXXI.	Staunton, Va.	May, 1881	x.	1
XXXII.	Harrisburg, Pa.	October, 1881	x.	119
XXXIII.	Washington, D. C.*	February, 1882	x.	225
XXXIV.	Denver, Col.	August, 1882	xi.	1
XXXV.	Boston, Mass.*	February, 1883	xi.	217
XXXVI.	Roanoke, Va.	June, 1883	xii.	3
XXXVII.	Troy, N. Y.	October, 1883	xii.	175
XXXVIII.	Cincinnati, O.*	February, 1884	xii.	447
XXXIX.	Chicago, Ill.	May, 1884	xiii.	1
XL.	Philadelphia, Pa.	September, 1884	xiii.	285
XLI.	New York, N. Y.*	February, 1885	xiii.	585

* Annual meeting for the election of officers. The rules were amended at the Chattanooga meeting, May, 1878, changing the annual election from May to February.

† Begun in May at Easton, Pa., for the election of officers, and adjourned to Philadelphia.

Number.	Place.	Date.	Transactions. Vol.	Page
XLII.	Chattanooga, Tenn	May, 1885	xiv.	1
XLIII.	Halifax, N. S.	September, 1885	xiv.	307
XLIV.	Pittsburg, Pa.*	February, 1886	xiv.	587
XLV.	Bethlehem, Pa	May, 1886	xv.	lxiii.
XLVI.	St. Louis, Mo	October, 1886	xv.	lxx.
XLVII.	Scranton, Pa.*	February, 1887	xv.	lxxvii.
XLVIII.	Utah and Montana	July, 1887	xvi.	xvii.
XLIX.	Duluth, Minn	July, 1887	xvi.	xxiv.
L.	Boston, Mass.*	February, 1888	xvi.	xxviii.
LI.	Birmingham, Ala	May, 1888	xvii.	xix.
LII.	Buffalo, N. Y.	October, 1888	xvii.	xxiv.
LIII.	New York, N. Y.*	February, 1889	xvii.	xxxi.
LIV.	Colorado	June, 1889	xviii.	xvii.
LV.	Ottawa, Canada	October, 1889	xviii.	xxiv.
LVI.	Washington, D. C.*	February, 1890	xviii.	xxx.
LVII.	New York, N. Y.	September, 1890	xix.	vii.
LVIII.	New York, N. Y.*	February, 1891	xix.	xxv.
LIX.	Cleveland, O.	June, 1891	xx.	xvi.
LX.	Glen Summit, Pa	October, 1891	xx.	lxi.
LXI.	Baltimore, Md.*	February, 1892	xxi.	xix.
LXII.	Plattsburgh, N. Y	June, 1892	xxi.	xxxiii.
LXIII.	Reading, Pa	October, 1892	xxi.	xliv.
LXIV.	Montreal, Canada*	February, 1893	xxi.	lii.
LXV.	Chicago, Ill.	August, 1893	xxii.	xiii.
LXVI.	Virginia Beach, Va.*	February, 1894	xxiv.	xvii.
LXVII.	Bridgeport, Conn	October, 1894	xxiv.	xxxv.
LXVIII.	Florida†	March, 1895	xxv.	xix.
LXIX.	Atlanta, Ga	October, 1895	xxv.	xxxiii.
LXX.	Pittsburg, Pa.*	February, 1896	xxvi.	xvii.
LXXI.	Colorado	September, 1896	xxvi.	xxix.
LXXII.	Chicago, Ill.	February, 1897	xxvii.	xvii.
LXXIII.	Lake Superior	July, 1897	xxvii.	xxx.
LXXIV.	Atlantic City, N. J.*	February, 1898	xxviii.	xvii.
LXXV.	Buffalo, N. Y.	October, 1898	xxviii.	xxxvi.
LXXVI.	New York City*	February, 1899	xxix.	xvii.
LXXVII.	California	September, 1899	xxix.	xlix.
LXXVIII.	Washington, D. C.*	February, 1900	xxx.	xix.
LXXIX.	Canada	August, 1900	xxx.	xlv.
LXXX.	Richmond, Va.*	February, 1901	xxxi.	xix.
LXXXI.	Mexico	November, 1901	xxxii.	
LXXXII.	Part I., N. Y. City	February, 1902	xxxiii.	
LXXXII.	Part II., Phila., Pa.	May, 1902	xxxiii.	

* Annual meeting for the election of officers.

† Begun in February at New York City, for the election of officers, and adjourned to Florida.

PUBLICATIONS.

THE publications of the Institute comprise:

PAMPHLETS.

1. The minutes of the Proceedings of each Meeting.

2. Papers presented or read by title (for subsequent publication) at each Meeting. (In nearly all cases in which papers, the titles of which appear in the Proceedings, are not subsequently published, they have been withdrawn by the authors.) These papers are published separately in pamphlet form, and are marked "subject to revision." Beyond the edition distributed, without charge, to members and associates not in arrears, a small supply is retained to meet subsequent demand. There are no copies on hand of papers read before 1880. The stock is nearly complete from 1880. These papers are for sale at the office of the Secretary, or are sent to purchasers by mail or express, charges paid, on receipt of the price, as follows:

No. of Pages.	Single Copies.	10 Copies.	20 Copies.
8 or less	\$0 10	\$0 60	\$1 00
9 to 12 inclusive	0 10	0 80	1 40
13 to 16 "	0 12	1 00	1 75
17 to 20 "	0 16	1 25	2 25
21 to 24 "	0 20	1 50	2 75
25 to 40 "	0 25	2 00	3 50
41 to 56 "	0 30	2 50	4 50
57 to 72 "	0 35	3 00	5 00
73 to 88 "	0 40	3 25	5 25
89 to 104 "	0 45	3 50	6 00
105 to 120 "	0 50	3 75	6 25

Papers with folders and inserted plates subject to special price.

TRANSACTIONS.

The volumes of *Transactions*, which are published annually, contain the list of officers, rules, etc., the Proceedings, and the papers revised for final publication. (In this revision, after the preliminary publication, authors are permitted to use the largest liberty; and the changes and additions made in papers are sometimes important. It should be borne in mind by those who study or quote a paper in the preliminary edition, that they may not have in that form the ultimate and deliberate expression of the author's views. It should be added, however, that in the majority of cases there are no important changes.) These volumes are for sale as follows, in paper covers:

Vols. I. to IV., inclusive, each,	$3 00
Vols. V. to VIII., inclusive, each,	4 00
Vols. IX. and X. (a small supply only on hand),	10 00
Vols. XI. to XXIX., inclusive, each,	5 00
Vols. XXX. and XXXI., each,	6 00
Vol. XXXII.,	5 00

Half-morocco binding, in all cases, $1 extra per volume.

INDEXES AND SPECIAL EDITIONS.

Index, Vols. I. to XV., inclusive, of the *Transactions*, cloth,	$1 00
Index, Vols. XVI. to XX., inclusive, paper,	1 00
Index, Vols. XXI. to XXV., inclusive, cloth,	1 25
Index, Vols. XXVI. to XXX., inclusive, cloth,	1 50
Indexes, Vols. I. to XV. and XVI. to XX., bound in one volume, cloth,	2 00
Indexes, Vols. I. to XV., XVI. to XX., and XXI. to XXV., bound in one volume, cloth,	3 00
Indexes, Vols. I. to XV., XVI. to XX., XXI. to XXV., XXVI. to XXX., bound in one volume, cloth,	4 00
"Bulletins" Nos. 1 and 2, containing analytical catalogues of Contributions to Mineralogy in 1899 and 1900 respectively, prepared by S. Harbert Hamilton and James F. Withrow, Philadelphia, Pa., each,	0 25

"The Genesis of Ore-Deposits," comprising the famous treatise of the late Professer Franz Posepny, with the successive discussions thereof by Le Conte, Blake, Winchell, Church, Emmons, Becker, Cazin, Rickard and Raymond (all of which were published in Volumes XXIII. and XXIV. of the *Transactions* of the Institute, and subsequently in the special "Posepny Volume," issued by the Institute); also, later papers by Van Hise, Emmons, Weed, Lindgren, Vogt, Kemp, Blake, Rickard and others, and the discussions of these papers by De Launay, Beck, and many others (some of these were included in Volume XXX. and the balance will appear in Volume XXXI.); also a complete bibliography of the Institute papers and discussions on this subject from 1871 to the present time.

The original Posepny volume comprised 265 pages, and was sold for $2.50, at which price the edition was long since exhausted. The present volume is an octavo of about 825 pages, bound in "book-linen," of the same color as the standard binding of the *Transactions*, . . 6 00

"The Evolution of Mine-Surveying Instruments." This

is a volume of about 400 pages, issued in the same style as the foregoing, and containing the original paper of Mr. Dunbar D. Scott on that subject (*Transactions*, XXVIII.), first published in 1898, together with later papers, continuing the same subject, and discussions thereof, by Hoskold, Lyman, Davis and many others, . $3 50

Geological Map of the United States, colored after the scale proposed by the International Geological Congress, by Prof. C. H. Hitchcock, ... 1 00

Memorial of Alexander L. Holley, with portrait, cloth, . 1 00

Glossary of Mining and Metallurgical Terms (1881), cloth, 50

List of Members, Rules, etc., paper, ... 50

Authors' Editions of Pamphlets.

Extra copies, when ordered before the printing of the pamphlet edition, are furnished to authors, under Rule VII., at the following rates:

No. of Pages.	50 Copies.	100 Copies.	250 Copies.	Each additional 100 copies above 250.
4 or less	$1 25	$1 50	$2 25	$0 50
5 to 8 inclusive	1 75	2 25	3 25	0 75
9 to 12 "	2 25	3 00	4 25	1 00
13 to 16 "	2 75	3 75	5 25	1 25
17 to 20 "	3 25	4 50	6 25	1 50
21 to 24 "	3 75	5 25	7 25	1 75
25 to 28 "	4 25	6 00	8 25	2 00
29 to 32 "	4 75	6 75	9 25	2 25
Covers (including printing on first page of the same), extra	1 50	2 00	3 00	0 50

Papers with folders and inserted plates subject to special price.

All communications and remittances should be addressed to R. W. Raymond, Secretary, 99 John St., or P. O. Box 223, New York City.

RULES

ADOPTED MAY, 1873. AMENDED MAY, 1875, 1877, AND 1878, FEBRUARY, 1880, 1881, 1887, 1890, AND 1896.

I.

OBJECTS.

THE objects of the AMERICAN INSTITUTE OF MINING ENGINEERS are to promote the arts and sciences connected with the economical production of the useful minerals and metals, and the welfare of those employed in these industries, by means of meetings for social intercourse, and the reading and discussion of professional papers, and to circulate, by means of publications among its members and associates, the information thus obtained.

II.

MEMBERSHIP.

The Institute shall consist of Members, Honorary Members, and Associates. Members and Honorary Members shall be professional mining engineers, geologists, metallurgists, or chemists, or persons practically engaged in mining, metallurgy, or metallurgical engineering. Associates shall include all suitable persons desirous of being connected with the Institute, and duly elected as hereinafter provided. Each person desirous of becoming a member or associate shall be proposed by at least three members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) upon receiving three-fourths of the votes cast, and shall become a member or associate on the payment of his first dues. Each person proposed as an honorary member shall be recommended by at least ten members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) on receiving nine-tenths of the votes cast; *Provided*, that the number of honorary members shall not exceed twenty. The Council may at any time change the classification of a person elected as associate, so as to make him a member, or *vice versa*, subject to the approval of the Institute. All members and associates shall be equally entitled to the privileges of membership; *Provided*, that honorary members shall not be entitled to vote, and members or associates whose post-office address shall be outside of the United States, Canada and Mexico shall not be entitled to vote by mail, except upon proposed amendments to the Rules.

Any member or associate may be stricken from the list on recommendation of the Council, by the vote of three-fourths of the members and associates present at any annual meeting, due notice having been mailed in writing by the Secretary to the said member or associate.

III.

DUES.

The dues of members and associates shall be ten dollars, payable upon their election, and ten dollars per annum thereafter, payable in advance on the first day of each calendar year. Honorary members shall not be liable to dues. Any member or associate not in arrears may become by the payment of one hundred dollars at one time a life-member or associate, and shall not be liable thereafter to annual dues. Any member or associate in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members when in arrears for one year; *Provided*, that he may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

IV.

OFFICERS.

The affairs of the Institute shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, a Secretary and a Treasurer, who shall be elected from among the members and associates of the Institute at the annual meetings, to hold office as follows:

The President, the Secretary, and the Treasurer for one year (and no person shall be eligible for immediate re-election as President who shall have held that office subsequent to the adoption of these rules, for two consecutive years), the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected. At each annual meeting a President, three Vice-Presidents, three Managers, a Secretary, and a Treasurer shall be elected, and the term of office shall continue until the adjournment of the meeting at which their successors are elected.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Council or the Institute; and the Council may in its discretion require bonds to be given by the Treasurer. At each annual meeting the Council shall make a report of proceedings to the Institute, together with a financial statement.

Vacancies in the Council may occur by death or resignation; or the Council may, by a vote of the majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings or perform the duties of his office. All vacancies shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *Provided*, that the said appointment shall not render him ineligible at the next annual meeting.

Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may he transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to

the approval of a majority of the Council, subsequently given in writing to the Secretary, and recorded by him with the minutes.

V.

ELECTIONS.

The annual election shall be conducted as follows: Nominations may be sent in writing to the Secretary, accompanied with the names of the proposers, at any time not less than thirty days before the annual meeting; and the Secretary shall, not less than two weeks before the said meeting, mail to every member or associate (except honorary members) a list of all the nominations for each office so received, together with a copy of this rule, and the names of the persons ineligible for election to each office; and if the Council, or a Committee thereof, appointed for the purpose, shall have recommended any nominations, such recommendation may also be sent to members and associates with the said list of all nominations made, but not upon the same paper. And each member or associate, qualified to vote, may vote, either by striking from or adding to the names of the said list, leaving names not exceeding in number the officers to be elected, or by preparing a new list, signing said altered or prepared ballot with his name, and either mailing it to the Secretary or presenting it in person at the annual meeting; *Provided*, that no member or associate in arrears since the last annual meeting shall be allowed to vote until the said arrears shall have been paid. The ballots shall be received and examined by three Scrutineers, appointed at the annual meeting by the presiding officer; and the persons who shall have received the greatest number of votes for the several offices shall be declared elected, and the Scrutineers shall so report to the presiding officer. The ballots shall be destroyed, and a list of the elected officers, certified by the Scrutineers, shall be preserved by the Secretary.

VI.

MEETINGS.

The annual meeting of the Institute shall take place on the third Tuesday of February, at which a report of the proceedings of the Institute and an abstract of the accounts shall be furnished by the Council. Other meetings shall be held in each year, at such times and places as the Council shall select, and notice of all meetings shall be given by mail, or otherwise, to all members and associates, at least twenty days in advance.

Every question which shall come before any meeting of the Institute, shall be decided, unless otherwise provided by these Rules, by the votes of a majority of the members then present. Any member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

VII.

PAPERS AND PUBLICATIONS.

The Council shall have power to decide on the propriety of communicating to the Institute any papers which may be received, and they shall be at liberty, when they think it desirable, to direct that any paper read before the Institute shall

be printed in the *Transactions*. Intimation, when practical, shall be given, at each general meeting, of the subject of the paper or papers to be read, and of the questions for discussion at the next meeting. The reading of papers shall not be delayed beyond such hour as the presiding officer shall think proper; and the election of members or other business may be adjourned by the presiding officer, to permit the reading and discussion of papers. The published papers and volumes of *Transactions* shall be distributed to all members and associates not in arrears, and may be sold to the public upon such conditions as the Council shall prescribe; but the Council may, in its discretion, omit sending to members and associates outside of the United States, Canada and Mexico, special circulars, unless the same contain proposed amendments to the Rules.

The copyright of all papers communicated to, and accepted by, the Institute, shall be vested in it, unless otherwise agreed between the Council and the author. The author of each paper read before the Institute shall be entitled to twelve copies, if printed, for his own use, and shall have the right to order any number of copies at the cost of paper and printing, provided said copies are not intended for sale. The Institute is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions at its meetings, and it is understood that papers and discussions should not include matters relating to politics or purely to trade; nor shall the Council or the Institute officially approve or disapprove any technical or scientific opinion or any proposed enterprise outside the management of the meetings, discussions and publications of the Institute, as provided in these Rules; *Provided*, however, that committees may be appointed by the Council or the Institute to make investigations and submit reports at meetings of the Institute; but no action shall be taken binding the Institute for or against the conclusions of any such reports.

VIII.

AMENDMENTS.

These Rules may be amended at any annual meeting by a two-thirds vote of the members present; *Provided*, that written notice of the proposed amendment shall have been given at a previous meeting; *and Provided, also*, that the amendment or amendments so adopted shall be printed upon a ballot and sent, not later than the next distribution of printed matter, to all members and associates not in arrears for the preceding year (except honorary members and foreign members elected before February, 1880), and each person receiving the same shall be requested to return it to the Secretary with his written vote of Yes or No to each amendment, and his signature; and the President shall appoint as Scrutineers three members or associates, who shall examine all of the said ballots which shall have been returned within one month from the date of their distribution, and shall report the result; and the Secretary shall publish and distribute to members, not later than the next distribution of printed matter, an announcement of the said result so reported, together with the text of the additional or amended rule or rules so adopted; and the amendment or amendments approved by the majority of the ballots so returned and reported shall become part of these Rules from and after the publication of said announcement by the Secretary.

Proceedings of the Eightieth (Thirty-First Annual) Meeting, Richmond, Va., February, 1901.

Committees.

General Committee.—Wyndham R. Meredith, *Chairman;* R. A. Dunlop, *Secretary;* Archer Anderson, Thomas Atkinson, E. Lockert Bemiss, Robert M. Blankenship, Charles E. Bolling, Thomas Bolling, Jr., Robert S. Bosher, James N. Boyd, John P. Branch, John Stewart Bryan, Joseph Bryan, H. Landon Cabell, Hon. George L. Christian, Andrew H. Christian, Jr., Arthur B. Clarke, S. Dabney Crenshaw, W. E. Cutshaw, H. D. Eichelberger, Dr. Henry Froehling, Thomas F. Jeffress, Dr. Geo. Ben. Johnston, Clemens Catesby Jones, C. D. Langhorne, E. G. Leigh, Jr., Joseph L. Levy, A. J. Marcuse, Milton E. Marcuse, Peter H. Mayo, Gustavus Millhiser, Samuel T. Morgan, Hill Montague, L. Z. Morris, Junius A. Morris, E. T. D. Meyers, Jr., B. B. Munford, Virginius Newton, William H. Palmer, John B. Purcell, Norman V. Randolph, George W. Stevens, C. W. Tanner, S. W. Travers, William R. Trigg, Henry Lee Valentine, John Skelton Williams.

Executive Committee.—L. Z. Morris, *Chairman;* H. L. Cabell, A. B. Clarke, H. D. Eichelberger, Virginius Newton, W. R. Trigg, Henry Lee Valentine, Wyndham R. Meredith, R. A. Dunlop.

Civic Committee.—Gov. J. Hodge Tyler, *Chairman;* Mayor Richard M. Taylor, Wilfred E. Cutshaw, Hon. B. B. Munford.

Finance Committee.—H. L. Cabell, *Chairman;* R. S. Bosher, James N. Boyd, John P. Branch, T. F. Jeffress, Dr. Geo. Ben. Johnston, Gustavus Millhiser, John B. Purcell, G. W. Stevens.

Hotels Committee.—H. D. Eichelberger, *Chairman;* R. M. Blankenship, Hill Montague, Junius A. Morris, C. W. Tanner.

Programme Committee.—A. B. Clarke, *Chairman;* R. M. Blankenship, John Stewart Bryan, Dr. Henry Froehling, Joseph L. Levy, M. E. Marcuse, N. V. Randolph.

Banquet Committee.—Virginius Newton, *Chairman;* Thomas Bolling, Jr., A. H. Christian, Jr., Clemens Catesby Jones, P. H. Mayo, S. T. Morgan.

Excursion Committee.—Henry Lee Valentine, *Chairman;* C. E. Bolling, S. Dabney Crenshaw, Clemens Catesby Jones, A. J. Marcuse, S. W. Travers.

Reception Committee.—W. R. Trigg, *Chairman;* Archer Anderson, Thomas Atkinson, E. L. Bemiss, C. E. Bolling, R. S. Bosher, John P. Branch, John Stewart Bryan, Joseph Bryan, Henry L. Cabell, A. H. Christian, Jr., Hon. Geo. L. Christian, Wilfred E. Cutshaw, H. D. Eichelberger, Dr. Geo. Ben. Johnston, E. G. Leigh, Jr., C. D. Langhorne, M. E. Marcuse, P. H. Mayo, W. R. Meredith, L. Z. Morris, E. T. D. Myers, Jr., Virginius Newton, William H. Palmer, John B. Purcell, George W. Stevens, S. W. Travers, Henry Lee Valentine, John Skelton Williams.

Hotel Headquarters.—The Jefferson Hotel.

The opening session was held Tuesday evening, February 19th, in the roof-garden of the Jefferson Hotel. Mr. Wyndham

R. Meredith, Chairman of the General Local Committee, briefly welcomed the visiting members to Richmond on behalf of Gov. Tyler, whose attendance was prevented by illness.

In the absence of the President, the chair was taken by ex-President R. H. Richards, but, at a later period of the session, was resigned to President Douglas, whose arrival (from Arizona) had been delayed.

Messrs. B. F. Fackenthal, Jr., Thomas M. Eynon and A. W. Sheafer were appointed Scrutineers to examine ballots received by mail, and to report the result at a later session.

The Secretary announced the receipt of copies of the following pamphlets for distribution to members:

Notes on a bill to establish a National Standardizing Bureau, printed for the Committee on Coinage, Weights and Measures of the House of Representatives (from the U. S. Coast and Geodetic Survey).

Description of the White Briquetting-Press (from the Henry S. Mould Co., of Pittsburg, Pa.).

A Treatise on Wood-Preservation (from the Barschall Impregnating Co., of New York City).

The following paper was presented in oral abstract by the Secretary, in the absence of the author:

The Great Oil-Well near Beaumont, Texas, by A. F. Lucas, of Beaumont, Texas.

In connection with this paper, samples of the crude oil, and of the fossiliferous rock thrown out by the "oil-geyser" in its initial eruption, photographic views of the well in full eruptive activity, and drawings of the apparatus by means of which it was controlled, were exhibited, and reports on the fossils and on the chemical analysis of the oil were read.

President James Douglas gave a lecture on the Paris Exposition of 1900,* with special reference to the mining and metallurgical industries of the nations there represented, and exhibited in illustration of his remarks a large number of lantern-views.

The second session was held in the same place, Wednesday morning, February 20th, President Douglas presiding.

* Not intended for publication.

The Secretary presented invitations to members of the Institute from the Robert E. Lee Camp, No. 1, Confederate Veterans, and the Commonwealth and Westmoreland Clubs, of Richmond.

The Scrutineers reported that the following officers had been elected:

PRESIDENT.

Eben E. Olcott,	New York City.

VICE-PRESIDENTS.

(To serve two years.)

Carlos F. de Landero,	Pachuca, Mexico.
John E. Hardman,	Montreal, Canada.
John Hays Hammond,	Denver, Colo.

MANAGERS.

(To serve three years.)

George A. Crocker,	New York City.
Horace V. Winchell,	Butte, Mont.
Clemens Catesby Jones,	Richmond, Va.

TREASURER.

Theodore D. Rand,	Philadelphia, Pa.

SECRETARY.

Rossiter W. Raymond,	New York City.

C. W. Hayes, U. S. Geol. Survey, made some remarks on The Mineral Resources of Virginia, illustrated by the corresponding sheets of the U. S. Geol. Survey maps.*

The following papers were read and discussed:

The D'Auria Air-Compressor, by Henry G. Morris, Philadelphia, Pa.

The History and Conditions of Mining in the Richmond Coal-Basin, by J. B. Woodworth, Cambridge, Mass.

Specifications for Steel Rails, by William R. Webster, Philadelphia, Pa.

Finishing-Temperatures for Steel Rails, by R. W. Hunt, Chicago, Ill.

After discussion of these papers, including the reading of communications on the subject by the Secretary, the session was adjourned.

---

* Intended for the information of members attending the meeting, and not for publication.

The third session was held Wednesday evening, February 20th, when the following papers were read:

The Deposits of Copper-Ores at Ducktown, Tenn., by Prof. J. F. Kemp, Columbia University, New York City.

The Ship-building Establishment of the William R. Trigg Co., Richmond, Va., by E. D. T. Myers, Jr., Richmond, Va.*

The fourth session, held Thursday morning, February 21st, was devoted chiefly to the discussion of the subject of Ore-Deposits, particularly in connection with the papers upon that subject presented at the Washington meeting, February, 1900.

In the absence of the author, the Secretary read the following paper:

The Caliche of Southern Arizona; an Example of Deposition by the Vadose Circulation, by W. P. Blake, Tucson, Ariz.

The following papers, and communications offered as contributions to this discussion, were presented in printed form:

Problems in the Geology of Ore-Deposits, by J. H. L. Vogt, Kristiania, Norway.

Contribution from Prof. Richard Beck, Freiberg, Saxony.

Discussion of Papers of Messrs. Emmons and Weed, by L. de Launay, Paris, France.

The Origin of Ore-Deposits (Discussion of Van Hise), by H. Foster Bain, Washington, D. C., and C. R. Keyes, Des Moines, Iowa.

The Genesis of Ore-Deposits (Discussion of Messrs. Emmons and Weed), by Arthur L. Collins, Telluride, Colo.

The following papers were read in abstract by their authors, in continuation of the discussion:

The Rôle of Igneous Rocks in the Formation of Veins, by Prof. J. F. Kemp, New York City.

The Character and Genesis of Certain Contact-Deposits, by Waldemar Lindgren, Washington, D. C.

---

* This paper, which was illustrated with lantern-views, was intended, not to be published by the Institute, but to prepare the visiting members for their inspection of the works named. Yet, although not directly related to mining or metallurgy, it proved in the highest degree interesting to all engineers, as a description of remarkably ingenious, rapid and cheap methods of construction, reflecting much credit, not only upon the enterprising proprietors of the works, but also, and especially, upon the author of the paper, who, as their engineer, planned and directed the operations described.

The discussion was further continued by Messrs. S. F. Emmons, B. B. Lawrence, and others (including a communication from Prof. F. D. Adams, McGill University, Montreal, Canada, read by the Secretary).

The annual report of the Council was then presented, as follows:

Annual Report of the Council.

In accordance with the rules, the Council makes the following report to the Institute:

The financial statement of the Secretary and the Treasurer shows receipts from all sources for the year ending December 31, 1900 (including the balance of $2262.82 on hand December 31, 1899), of $34,369.54, and expenditures of $32,891.42, leaving $1478.12 cash on hand. No account is taken in this statement of the increased value of the assets of the Institute in back-volumes of the *Transactions*, office-furniture, etc. In addition to the cash on hand, the Institute possesses invested funds of the par value of $15,900 and market-value of more than $20,000, yielding about $1000 interest annually.

The detailed statement is as follows:

Receipts.

Balance from statement,		$2,262 82
Annual dues,	$24,005 53	
Life-membership,	2,886 80	
Binding of *Transactions*,	2,129 70	
Sale of publications,	2,022 55	
Electrotypes,	36 55	
Interest on bonds and deposits,	1,007 22	
Miscellaneous,	18 37	
		$32,106 72
		$34,369 54

Disbursements.

Printing volume xxix. of the *Transactions*,	$3,378 19
" pamphlet edition of papers,	3,836 17
" circulars and ballots,	237 96
Binding volume xxix. and miscellaneous volumes of *Transactions*,	2,123 67
" exchanges,	220 09
Engraving and electrotyping,	1,351 88
Secretary's department, including clerks, stenographers, and expenses of editing and proof-reading,	8,660 00
Carried forward,	$19,807 96

Brought forward,	$19,807 96	$34,369 54
Postage, including post-office box-rent,	2,015 17	
Stationery,	531 22	
Rent,	2,500 00	
Express and freight charges,	1,730 62	
Telephone,	159 51	
Telegrams, cablegrams and car fare,	65 69	
Office equipment,	482 45	
Assistant Treasurer's department,	4,094 02	
Storage of *Transactions*,	172 83	
Special stenographers and expenses of meetings,	722 92	
Office supplies and repairs,	379 25	
Insurance,	22 20	
Miscellaneous,	47 00	
Extra clerical help,	46 50	
Paris Exposition,	99 38	
Library addition,	14 70	
		$32,891 42
Balance,		$1,478 12

Volume xxix. of the *Transactions*, an octavo of 1176 pages, issued and distributed during the year, is one of the largest ever printed by the Institute, and is unquestionably equal to any of its predecessors in the value and variety of its contents.

Two meetings were held during the year: the annual meeting in February at Washington, D. C., and the Canadian meeting in August. The former was rendered notable by the presentation, largely by members of the U. S. Geological Survey, of papers on the formation of ore-deposits which have attracted much attention throughout the world, and the fruitful discussion of which, by the leading authorities in many countries, is now in progress, to the great enhancement of the repute of the Institute and the value of its *Transactions*. In other professional respects, and in social pleasures also, the Washington meeting was most successful.

The Canadian meeting, beginning technically at Quebec, was chiefly held in Nova Scotia, with sessions at Sydney, Cape Breton, and at Halifax. On this occasion, as the published Proceedings show, the Canadian Mining Institute and the Mining Society of Nova Scotia were the generous hosts of the Institute.

Changes in membership have taken place during the year as follows: 260 members and 13 associates have been elected; 9 associates have become members; the deaths of 6 of the old

class of "foreign members," 34 members and 3 associates have been reported; 33 members and 5 associates have resigned, and 53 members and 5 associates have been dropped from the roll by reason of non-payment of dues, loss of correct address, etc.*

These changes are tabulated as follows:

	H. M.	F. M.	M.	A.	Totals.
At date of last report	11	37	2437	180	2661
Gains: By Election			260	13	273
" " Change of Status			9		9
Losses: By Resignation			33	5	38
" " Dropping			53	5	58
" " Change of Status				9	9
" " Death		6	34	3	37
Total gains			269	13	282
Total losses			120	22	142
Present membership	11	31	2586	171	2799

The list of deaths reported during the past year comprises the following members and associates:

George T. Barnes (1884), H. L. Bridgman (1879), Arthur Richard Browne (1893), J. H. Bowden (1871), Park A. Buell (1900), Edward Button (1893), Alex. M. Byers (1886), John Carkeek (1893), Henry M. Curry (1879), John M. Desloge (1881), E. B. Dorsey (1879), Thomas Egleston (1871), H. C. Freeman (1878), Mellen S. Harlow (1895), James Hemphill (1875), William Henry Jessop (1892), Samson Jordan (1876), George Labram (1896), William J. M. Larnach (1887), Henry McCormick (1874), Charles A. Martine (1879), H. B. C. Nitze (1888), Franklin Platt (1872), Addison C. Rand (1876), Jasper R. Rand (1882), George Richards (1875), John H. Ricketson (1872), J. E. Schwartz (1876), L. I. Seymour (1893), Hamilton Smith (1877), Arthur B. Stoddard (1891), F. W. Taunton (1900), John L. Thomson (1893), James W. Tyson (1886), George H. F. Ulrich (1890), Frederick M. Watson (1887), H. Walter Webb (1882), John Wister (1898), Thomas W. Yardley (1883).

Of these, Messrs. Egleston, Jordan, Nitze and Tyson have been made the subjects of special Biographical Notices, which will be separately published. Concerning the remainder of the

* Many of these, no doubt, will be reinstated, as has been the case in former years.

list the following data, comprising what the Secretary has been able to obtain, are here placed on record. Any appropriate facts concerning names not here mentioned, which may be received hereafter, will be accepted with thanks, and included in the next annual report.

George T. Barnes was born, 1846, in Philadelphia, where he died January 30, 1900. Educated at the Central High School, he started, about thirty years ago, as an importer of iron-ore, of which business he became one of the leading American representatives. Of late years he was chiefly concerned in the importation of Spanish and African ores, and to that end established a line of steamers, known by his name, for the shipment of iron- and manganese-ores from Mediterranean ports to Philadelphia and Baltimore. Mr. Barnes was for many years the treasurer of the Crane Iron Company and president of the Catasauqua and Fogelsville Railway. He was also connected with the firm of William R. Hart & Co., and a member of the executive committee and board of directors of the American Pig Iron Warrant Storage Company. He was a member of the Institute since 1884.

H. L. Bridgman was born, 1854, at Keokuk, Iowa, received his preliminary education in that town and Racine, Wis., and subsequently studied at the School of Mines of Clausthal, Germany. Upon his return to America he was first employed at the Iron silver-mine, Leadville, Colo. In 1883 he came to Chicago, where, as one of the first to introduce and perfect the electrolytic refining of copper, he was for several years superintendent of the works (at Blue Island, Ill.) of the Chicago Copper Refining Co., which he had been instrumental in organizing for the practice of this method. While occupying this position, he invented an ingenious machine for the mechanical sampling of ores, etc., which he described in an able and interesting paper presented in 1891 to the Institute (*Trans.*, xx., 416), of which he had become a member in 1879. In 1898 he went to Mexico, where he successfully conducted explorations and mining operations in the State of Nuevo Leon until obliged by failure of health to return to his home at Blue Island, where he died, September 20, 1900.

Arthur Richard Browne, born 1866, in England, and professionally educated as mining engineer at Freiberg, Saxony,

was engaged for ten years in Tasmania, South and West Australia, and other Australasian colonies, in managing as well as inspecting and reporting upon mining properties. The last two years he spent in British Columbia as the mining inspector, ore-purchaser, etc., of a London firm, and reporting on properties and buying ore. He was a Fellow of the Royal Society, Tasmania, Fellow of the Geological Society, a member of the Institute of Mining and Metallurgy of London, and member of various other professional societies. He joined the Institute in 1893. He died April 26, 1900, at the early age of 34.

J. H. Bowden, born at Penzance in Cornwall, England, in 1846, came to this country as a child with his parents, who settled in Tamaqua, Pa. After learning his trade as a machinist, he took at Philadelphia a technical course, graduating as a mechanical engineer. In 1869 he became superintendent of the Wyoming Valley shops at Wilkes-Barre, and three years later formed a partnership with Irving A. Stearns for general engineering work. In 1873 he was appointed chief engineer of the Susquehanna Coal Co., a position which he held subsequently for all the coal companies connected with the Pennsylvania R. R. He was also borough engineer of Nanticoke, Pa., from the time of its incorporation. He was the owner of several patents, the most important of which is the Bowden self-oiling car-wheel, now extensively used in the coal-regions. He had recently completed, for publication in the forthcoming History of the Pennsylvania R. R., an exhaustive record of the anthracite coal-mining industry of Pennsylvania, including an account of all the coal companies now under the management of the Pennsylvania R. R. Co.

Mr. Bowden joined the Institute at its Bethlehem meeting in August, 1871. He contributed the following papers to the *Transactions:* "Biographical Notice of Erich C. Schaufuss" (*Trans.*, xvii., 419); and "Tandem-Tanks for Hoisting Water from Flooded Slopes" (*Trans.*, xx., 343). He was also a member of the American Society of Mechanical Engineers. His death occurred November 16, 1900.

Park A. Buell was born in West Richfield, Ohio, September 13, 1859, and removed at the age of 15 to California. In 1881 he established at Stockton the lumber business of P. A.

Buell & Co., of which he was managing agent and treasurer until his death. He was also president of the Brown Mining Co., of Tuttletown, Tuolumne county, organizer and president of the commercial association which effected the construction of the San Francisco and San Joaquin Valley railroad, director of the Jackson, Sutter and Amador Railway Co., and prominently identified with other railways and commercial enterprises. He was a delegate to the Nicaragua Canal convention at Kansas City in 1898. He became a member of the Institute early in 1900, and died April 4th of the same year.

Edward Button, who was born in 1835 and died May 24, 1900, at Pietermaritzburg, Natal, South Africa, spent many years in exploring Natal and the Transvaal. He was one of the early pioneers in that country, where he was associated with such well-known explorers as Thomas Baines and Thomas McLachlan, and discovered the famous reef "Natalia" in the Zoutpansberg district. He joined the Institute in 1893.

Alexander M. Byers was born at Greenfield Farm, Mercer county, Pa., September 6, 1827. After a short schooling, he found work at the old Henry Clay furnace in Mercer county, and, having gained some practical experience, went to Pittsburgh, where, in 1865, after eight years' connection with the firm of Spang & Co., he formed a partnership with his brother for the manufacture of wrought-iron pipe. This venture was successful from the beginning, and, through the possession of many valuable patents and secret processes for the manufacture of pipe, soon became one of the leading establishments of the country, and the largest producer outside of the National Tube Co. Some years ago Mr. Byers started the Girard furnace at Girard, Ohio, which is still in operation. He was at one time interested with Tod, Stambaugh & Co., of Cleveland, in the Biwabik mine, Minn.; and he was largely interested in the various Westinghouse enterprises, and in the utilization of natural gas. He joined the Institute in 1884. His death from heart-disease occurred September 19, 1900.

Henry M. Curry was born in 1847 at Pittsburgh, Pa., where he died May 5, 1900. After the Civil War, through which he served in the Union army, he began business as a broker's clerk; but his energy and ability led to his appointment as superintendent of the Upper Union mills of the Carnegie Brothers'

Co. In 1872 he was transferred to the Lucy furnace as manager, and afterwards to the charge of the ore-department of the city sales-office, one of the most responsible positions in the company. When the Carnegie-Phipps Company, Limited, was organized, he was made vice-chairman. Upon the formation of the Carnegie Steel Company, he became manager of the furnace-department, and held that position until recently. He was one of the few early partners of Andrew Carnegie who remained actively engaged with the Carnegie interests. He resigned from the Carnegie board with H. C. Frick in 1900, though he still retained his interest in the company. He became a member of the Institute in 1879.

John M. Desloge, born in 1849 at Potosi, Washington county, Mo., was educated at the St. Louis High School, and adopting mining as his profession, became assistant superintendent of the Desloge Lead Co.'s works at Bonne Terre, Mo., and retained that position until the transfer of the business to the St. Joseph Lead Co. in 1886. After several years spent in the West, in the examination and development of mining properties, he returned to Bonne Terre in 1891 as superintendent of the Desloge Consolidated Lead Co., developing its mining property and erecting its present plant and works. He joined the Institute in 1881, and took occasional part in the discussions. His death occurred September 7, 1900.

Edward Bates Dorsey, born 1833 in England, began early his career as an engineer. In 1852–54 he assisted the late Alfred Duvall in his surveys of Northern Peru, and afterwards became superintendent of the mines of Don Bernadino Codecido in Chile, where he remained several years. In 1859 he went to California, and from 1861 to 1864 was superintendent and part-owner of the Mexican mill at Empire City, Nevada. He examined and reported, chiefly for English clients, on many mines in California, Nevada and South America. In 1880 he turned his attention more especially to railroad construction, and afterwards acted as consulting engineer for several large British investors in American railroads. He became in 1879 a member of the American Society of Civil Engineers, to which he contributed important papers on "Structural Steel" and "Irrigation." His series of three papers, comparing the construction, management and operating costs of English and

American railroads, won for him the Norman medal of that society in 1886. He was a member of the Institute from 1879 to the time of his death in February, 1900.

H. C. Freeman, born 1829 at Newark, N. J., served with distinction in the Civil War, becoming Chief Engineer of the 3d U. S. Army Corps. For a number of years after the war he resided in Alto Pass, Ill., and was connected with the Illinois Geological Survey. In 1869 he designed and supervised the construction of the plant of the Utica Cement Co. at La Salle, Ill. In 1896 he moved to Helena, Mont., where he practiced as a mining engineer until his death, November 3, 1900. Mr. Freeman joined the Institute in 1878; contributed the following papers to the *Transactions*: "The Hydraulic Cement Works of the Utica Cement Company, La Salle County, Ill." (*Trans.*, xiii., 172); "The La Plata Mountains, Colo." (*Trans.*, xiii., 681); and took part in the discussion of various other papers.

Mellen S. Harlow, born October 17, 1860, at East Hebron, Me., received his technical training as mechanical engineer at the Stevens Institute of Technology, Hoboken, N. J., from which he graduated in 1884. Shortly afterwards he was employed by the Ingersoll-Sergeant Drill Co., and in 1887 established and became manager of its Boston office. In 1893 he became a member of the American Society of Mechanical Engineers, and in the same year was sent to look after his company's interests in Johannesburg, South Africa. Upon his return, in 1895, he joined the Institute. His death occurred December 29, 1900.

James Hemphill was born July 22, 1827, at Mechanicsburg, Pa., and, after serving his apprenticeship as a blacksmith, went in 1850 to Pittsburgh, where he found employment at the Pittsburgh water-works, of which he afterwards became engineer. After several small ventures in mechanical industries, he formed in 1859, with H. F. Hart and the late W. S. McIntosh, a partnership, the modest shop of which grew to the famous Fort Pitt foundry of McIntosh, Hemphill & Co.

The enormous present development of the American steel industry is largely due to Mr. Hemphill's influence in forcing to the front the reversing blooming-mill. Reversing-mills for steel had previously been failures, principally because they

lacked mass and strength. The type of mill which he built and installed at the Pittsburgh Bessemer steel-works (the small plant from which the Homestead works of the Carnegie Steel Co. were afterwards developed) revolutionized the business, and was the model for all later mills.

It is worthy of record, as an evidence of Mr. Hemphill's integrity and sense of justice and fair dealing, that, during his long career as a manufacturer, there was not a single "strike" of the workmen employed by his establishment. This fact is affirmative proof of his wisdom and kindness, although, in these days of "sympathetic" strikes, and strikes for "recognition," equally wise and kind employers may have been less fortunate in their record of undisturbed harmony with their employees. Mr. Hemphill became a member of the Institute in 1875, very early in its history. His death occurred August 7, 1900.

George Labram was born in Detroit, Mich., about 1860. His father was a mechanical engineer employed in the copper- and iron-mines in the Lake Superior district, and the son naturally followed the same profession. He became connected with mines in Mexico, had charge of some of the works of the Silver King mine in Arizona, and was employed for some time by Fraser & Chalmers of Chicago in designing and erecting machinery built by them, notably the Harney Peak tin-ore reduction-works. In 1893 he was sent by this firm to erect and run a crushing-plant for the De Beers Consolidated Mines, Ltd., at Kimberley, South Africa. Three years latter he became chief engineer and electrician of that company. During the historic siege of Kimberley, which lasted 124 days (from Oct. 14, 1899, to Feb. 15, 1900) he rendered more assistance than any other man in the defence of the town against the Boers. From a 10-ft. billet of hammered mild steel, about 10.5 in. in diameter (originally intended for shafting) and several bars of 6- by 2.5-in. Low Moor iron, which happened to be in the possession of the De Beers Co., he constructed in 24 days a 4.1-in. siege-gun, under the disadvantages of entire personal ignorance of such work, and the lack of technical authorities, experienced assistants and suitable mechanical facilities—to say nothing of the discouragement and opposition offered by military experts. His scientific guides were the "Encyclopedia Britannica" and a couple of more or less pertinent text-books found in the town.

His workmen were members of the "town-guard," withdrawn from service in the outworks, a few of whom had previously been employed in English arsenals. The work was carried on under continuous heavy fire from the enemy.

The order authorizing the experiment was signed by Mr. Cecil Rhodes on the evening of Dec. 24, 1899; and on Jan. 19, 1900, the gun was in position for a preliminary trial. After a few necessary alterations, rapidly made, "Long Cecil" went finally into action Jan. 23, and, with a few minor accidents, promptly repaired, remained a most effective aid in the defence of the town (firing more than 250 29-lb. shells at ranges of from 5000 to more than 8000 yards) until the arrival of the relief-column, Feb. 15, 1900.

Unfortunately, the skillful and ingenious creator of "Long Cecil" did not witness that joyful event, having been killed in his room at the hotel, by the explosion of a 100-lb. Boer shell, on the evening of Feb. 9, 1900. In recognition of his distinguished service, the De Beers Co. has undertaken to provide for the education of his only son.

Mr. Labram became a member of the Institute in 1896, and has contributed to its *Transactions* only the story of American self-reliance, courage and resource which is outlined above with mingled pride and sorrow.

Henry McCormick was born in Harrisburg, Pa., March 10, 1831, and graduated from Yale College in 1852. After studying law for a year or two in his father's office, as a preparation for the extensive business enterprises he had in view, he took charge of the old Reading blast-furnace at Robesonia, Pa. In 1856 he assumed the management of the Henry Clay furnace at Columbia, Pa., but returned to Harrisburg in 1857 to operate the Paxton furnace, just purchased by his father. Another furnace was built later; and in 1866 extensive nail-works were erected at West Fairview, on the Susquehanna opposite Harrisburg, which were successfully operated by him for 23 years. He was also general director of other iron mills in South Harrisburg. He was a patriotic citizen, and served in the Civil War, in which he attained the rank of colonel.

Col. McCormick subsequently served as treasurer of the commission appointed to organize the new geological survey of Pennsylvania. He was president of several important cor-

porations, and active in public charities. He joined the Institute in 1874, when it was yet comparatively an unknown and problematical enterprise, and staunchly supported it until his death, 26 years later.

Charles A. Martine, born in Germany in 1838, received a thorough scientific education at the University of Goettingen. He came to America in 1858, and for a couple of years acted as assistant to his old friend Prof. Joy, at that time professor of chemistry at Columbia College, N. Y. At the outbreak of the Civil War he entered the Union service, and for four years was a Chief Engineer in the U. S. Navy. In 1865 he crossed the plains to Central City, Colo., and in the following summer went to Georgtown, where his knowledge of chemistry and metallurgy led him to make the first attempt to reduce the silver-ores of that district. The "What Cheer" mill of Garritt, Martine & Co., produced in 1867 the first silver bars made in Colorado. This enterprise antedates the metallurgical works of the late Senator Hill at Black Hawk; and to Mr. Martine belongs the credit of the first successful reduction into bullion of silver from the complex ores of Georgetown. In 1870 he formed a partnership with Messrs. G. W. Hall and Frank J. Marshall for the purchase of ore, and built a sampling-mill. He was intimately connected with the development of the Georgetown mines, and largely instrumental in placing the mining and treatment of the ores on a practical basis. Mr. Martine was a man of high scientific attainments, especially in metallurgy and mineralogy. He possessed the best books of reference, and kept himself well-informed from the leading journals in science, literature and art. He was an active member of the Colorado Scientific Society, and a member of the Institute since 1879. Though of exceedingly retiring disposition, he had a host of friends; and his cabin in Georgetown was a center of interest to Gen. Grant, Gen. Sherman, and many other distinguished visitors in the early days. His death occurred early in July, 1900.

Franklin Platt, born 1844 at Philadelphia, studied at the University of Pennsylvania, which he left at the outbreak of the Civil War to serve in the Union Army until peace was declared. In 1874 he was appointed an assistant geologist on the Pennsylvania Survey, and continued in that office until

1881, when he resigned to become president of the Rochester & Pittsburg Coal and Iron Co. He was also manager of the Adrian and Beech Tree mines in Pennsylvania. He contributed freely to many scientific publications, and prepared nine volumes of the Report of the Geological Survey of Pennsylvania. Mr. Platt joined the Institute in 1872.

Addison C. Rand was born September, 1841, in Westfield, Mass., where, in 1865, together with his elder brother Jasper, he succeeded to the business of his father, in the manufacture of whips. A few years later he came to New York, where another brother, Albert F. Rand, of the Laflin & Rand Powder Co., turned over to him, for investigation, various projects in rock-drilling machinery. Mr. Rand's mechanical insight enabled him to condemn as useless at least one scheme which had strong backing; and this investigation turned his attention to the whole subject of rock-drills. The Rand Drill Co. was organized in 1871 and incorporated in 1879, and attained a great business success, which was largely due to his intuitive knowledge and judgment of men, and his kind and agreeable personality, tact and urbanity. Mr. Rand was active in the organization of the Engineers' Club in New York, of which he was the treasurer from the beginning. He joined the Institute in 1876, and evinced thereafter a continuous and sympathetic interest in its progress, often attending its meetings, at which his genial presence was always welcome. He was also a member of the Chamber of Commerce, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and many prominent social clubs. He was likewise a director of the Ninth National Bank; of the Laflin & Rand Powder Co.; secretary-treasurer and director of the Rend-rock Powder Co.; treasurer and director of the Davis Calyx Drill Co.; president and director of the Pneumatic Engineering Co.; and president of the Rand Drill Co. His death occurred March 9, 1900.

Jasper Raymond Rand, brother of the above, was born September 17, 1837, in Westfield, Mass., and received his education in the schools of his native town and in Fairfax, Vt. He joined his father in the manufacture of whips, and upon the latter's retirement in 1865, succeeded, with his brother, to the business. In 1870 he removed to New York, and after an association with his brother Albert T. Rand in the Laflin &

Rand Powder Co. became treasurer of the newly organized Rand Drill Co. early in the '70's, a position which he held until his succession to the office of president on the death of his brother Addison C. Rand in March, 1900. The manufacture of rock-drills was in its pioneer stage, with a very uncertain future before it, when the Rands first became interested in it; but under their wise and skillful administration it has developed into an important industry. Rock-drills were among the first American machines to win recognition from foreign engineers; and their growing importance has finally made them an essential part of every mining outfit in every important mining country on the globe. In 1873 Mr. Rand took up his residence in Montclair, N. J., where he was honored with many local offices by his fellow citizens. He was interested in all public enterprises and contributed generously to their support. His membership in the Institute dates from 1882.

George Richards, born 1833 in Pottsville, Pa., became, at the age of eighteen, manager of all the Glendon Iron Co.'s mining interests in New Jersey, and held that position for upwards of 40 years. He was president of the Dover Iron Co., the Morris County Machine & Iron Co., of several local railroad companies, of the National Union Bank of Dover, of the Dover Printing Co. and of the George Richards Co. In 1871 he was appointed State director of the United Railroads of New Jersey, and for 16 years served as mayor of his town, and at various times filled other municipal and State offices. He became a member of the Institute in 1875, and died April 3, 1900.

John Howland Ricketson was born at New Bedford, Mass., September 21, 1837, graduated from Harvard College in 1859, and, for a time, studied law in Boston, completing his studies in Pittsburgh. In 1862 he gave up his legal practice and entered the old foundry-business of his father-in-law, Abram Garrison, established by the Garrison family in 1806. In 1890 the firm was incorporated as the A. Garrison Foundry Company. Upon the death of Mr. Garrison in 1894, Mr. Ricketson became president. He took a leading part in many important enterprises, especially in connection with bridge-building, and was officer or director of many financial and industrial concerns. Mr. Ricketson was deeply interested in public and political

affairs, possessed wide literary attainments, and enjoyed considerable fame as an orator, in which capacity he was repeatedly selected to represent his townsmen, as many members of the Institute (which he joined in 1872) still remember with pleasure. He died July 20, 1900.

James E. Schwartz, born 1843 in Allegheny, Pa , received his early business training with the lead-manufacturing firm of his father, Fahnestock, Schwartz & Hazlett; and, after his father's death and the dissolution of the old firm, went into the business himself. Later he abandoned the manufacture of white lead and began that of pig lead, which he carried on for many years. Though less than 20 years old at the outbreak of the Civil War, he enlisted in the Union Army, and was engaged in some of the fiercest battles of the war. Mr. Schwartz was actively interested in many branches of business, and at the time of his death, May 16, 1900, was president of the Pennsylvania Smelting Co. of Utah, president of the Pennsylvania Lead Co. of Pittsburgh, and a director of the Bank of Pittsburgh. He joined the Institute in 1876.

Louis Irving Seymour, born in 1860, began his career as a mechanical engineer. When only 23 years of age he was sent to superintend the erection of special machinery at the famous mine of El Callao, in Venezuela. Here he became acquainted with H. C. Perkins and Hamilton Smith, who soon recognized his remarkable ability, and five years afterwards he was appointed mechanical engineer to the De Beers Consolidated Mines. Before he was thirty he had revolutionized the vast and complicated mining-plant of these great diamond-mines. The winding-engines, designed and erected by him in 1892, hold the world's record of their class for hoisting (6500 tons of ore in 24 hours from a depth of 1300 feet to the surface). In 1893 he went to London and took charge of the Erith works of Fraser & Chalmers, Ltd., continuing to act as consulting engineer for the De Beers Co. and the Rand Mines, Ltd. In 1896 he became head engineer in the mechanical engineering department of Messrs. Eckstein & Co., on the Rand, a position of much responsibility, which was further enlarged two years later, when he succeeded Mr. Hennen Jennings as the engineer of H. Eckstein & Co. This carried with it the control of the leading gold-mines of the Rand, where he

was actively engaged when the Boer war broke out. He was one of the organizers of the Pioneer regiment at Capetown. This regiment was recruited almost entirely from engineers and mechanics of the Rand, with the idea of giving employment to skilled workmen, whose labor could be utilized in an engineering corps for the repair and construction of bridges, railways and buildings destroyed by the Boers in wanton savagery. Mr. Seymour received the commission of major in this corps, and was killed in action, July 14, 1900, to the great sorrow of all who knew him. He had been a member of the Institute since 1893.

Hamilton Smith was born near Louisville, Ky., in 1840, and received his first professional training at Cannelton, O. In 1870 he went to the Pacific coast, where he soon made his mark as engineer and manager of the Triunfo mines in Lower California, but chiefly in planning and constructing the hydraulic gold-mining works at the North Bloomfield Gravel and Milton mines in Nevada county, Cal. In addition to his work in hydraulic mining, he examined and reported on various mines on the Pacific coast, and made surveys of the New Almaden quicksilver-mines. He was largely instrumental in the establishment of the Vulcan Powder Works, and prominent also in the legal struggle between the miners and farmers relative to the *débris* from the hydraulic mines. When injunctions had been placed upon hydraulic mining, he went to New York, carefully studied the new water-supply scheme for the city, and made a serious bid for the contract. About this time he wrote his celebrated book "Hydraulics," considered by experts as high authority. In 1881 he made his first report for the Rothschilds on the El Callao mine, Venezuela, and afterwards, as consulting engineer, started its successful management under H. C. Perkins. In 1885 he established himself as mining engineer in London in a partnership with Mr. de Crano; and in the following year they founded, first with a capital of £20,000, later increased to £1,250,000, the company now known as the Exploration Co., Ltd., of which Mr. Smith was the managing director. In this capacity he took an active interest in South African gold-mining, and formed the Consolidated Deep Levels, Ltd., and the Transvaal General Association, Ltd. He visited South Africa in 1892 and 1895, and was one of the first to de-

clare that the deep levels, as well as the outcrop-mines, could be successfully worked. During these brief visits he obtained a remarkable insight into the possibilities of the Rand gold-fields, and in 1893 contributed an able article on the subject to the London *Times.* He promoted the Central London Electric Railway Co.; the establishment of Fraser & Chalmers' mining-machinery works at Erith; and the Alaska Treadwell Gold Mining Co. of London, of which he was consulting engineer. In 1895, after the death of Mr. de Crano, he formed a partnership with H. C. Perkins, his old friend and associate, and in 1896 came back to reside in the United States, and was actively engaged in the development of the Mariposa grant in California, and various other mining enterprises, at the time of his death by accidental drowning, July 4, 1900. He joined the Institute in 1877.

Frank William Taunton, born 1876 at Maritzburg, South Africa, was educated at Hilton College and the Capetown School of Mines, and completed his practical training at Kimberley, and in one of the Robinson mines at Johannesburg. He came to America for study and investigation of mining practice, but hurried home upon receiving the news that his father, a Major of the Natal Carbineers, had been killed at the front at the beginning of the Boer war. He entered the British military service, and died of enteric fever, June 15, 1900. Mr. Taunton became a member of the Institute only two months before his death.

John Landell Thomson was born in Glasgow, Scotland, and in his early life was associated with Mr. Thomas Gibb in the treatment of copper-ores by the Henderson wet process. In 1875 he came to Canada as assistant to his brother in the management of copper-mines at Capelton, near Sherbrooke, and later of the Huntingdon copper-mines at Dillonton, Quebec. Four years later he was appointed by the Orford Nickel and Copper Co. superintendent of its nickel-mines in Orford county, and its Crown copper-mine at Capelton, and in 1880, together with Henry M. Howe, constructed the Orford Raschette blast-furnace for smelting copper-ores. This improvement over the old style of square or round furnace soon increased the daily output threefold, and marked the turning-point in the history of copper-smelting, besides gaining world-wide fame for the Or-

ford company. In 1881 he assumed superintendence of this company's copper-works, near New York. He went to Butte, Montana, in 1883, where he had charge of the Garrat smelter, became associated with W. A. Clark, was instrumental in obtaining for him the United Verde copper-mines, and was for many years in charge of his mines in Butte and at Jerome, Arizona. A few years ago he returned to become superintendent of the Orford copper-works at Bayonne, N. J. At this time he devised and patented the Thomson process for smelting nickel, which enabled the Orford Co. to treat the magnificent deposits of nickel-ore at Sudbury, Ont., and gave them command of the nickel-markets of the world. Mr. Thomson joined the Institute in 1893, and his death occurred April 4, 1901.

Frederick M. Watson was born in Pennsylvania in 1866, and after graduation from the School of Mines, Columbia College, in 1885, filled various responsible positions in Mexico, Peru and elsewhere in South America. At the instance of Mr. John Hays Hammond he went to South Africa, where he became in 1896 general manager of the Simmer & Jack Proprietary mines, the largest mining venture in the Witwatersrand gold-fields. Under his management the company became the largest individual producer in South Africa. In 1899, after a severe attack of fever, Mr. Watson left the Co. to become a joint-manager of the Consolidated Gold-Fields; but his health again broke down, and he died at Cannes, France, in February, 1900. He became a member of the Institute in 1887.

H. Walter Webb, born 1852 at Tarrytown, N. Y., was graduated in 1873 from the Columbia School of Mines and in 1875 from the Columbia Law School. After an exploring-trip in South America, a brief practice at the bar, and an equally transitory experience as banker, he became in 1886 vice-president of the Wagner Palace Car Co., and subsequently assistant to Mr. Depew, President of the N. Y. Central. In 1890 he was elected third Vice-President of that Co. and put in charge of the operating-department of its passenger-service. Five months later occurred the great strike, when 5000 men quit work at the command of the Knights of Labor. Both Mr. Depew and Mr. Vanderbilt being absent, the whole burden of this crisis came upon Mr. Webb; and the victory which he won cost him dear, although, in spite of the serious

and permanent impairment of his health, he continued his active service for some years, and made many improvements in administration, including the establishment of fast passenger-trains, etc. From an attack of typhoid fever, in 1896, and a subsequent relapse during convalescence, he rallied, but never really recovered. His death occurred June 18, 1900.

Mr. Webb joined the Institute in 1882. In 1886 he was appointed a member of the N. Y. Board of Education, and served three years. He was a director in numerous financial and industrial institutions and railroad companies.

John Wister, born at Germantown, Pa., July 15, 1829, received his education at the Germantown academy, but left school in 1845 to become sales-agent with Fisher, Morgan & Co. at Duncannon, Pa. At the death of Mr. Fisher, his uncle, some years later, he became manager of the company until the formation of the Duncannon Iron Co. in 1857, of which he became treasurer and manager. He succeeded his father as president in 1883, and continued in that position until his death, June 4, 1900. Under his efficient management the plant grew from a small forge to a large and prosperous rolling-mill and nail-factory, which successfully weathered many financial panics. With his brother he established the Wister furnace at Harrisburg, Pa., in 1867, and continued to operate it until the property was purchased by the Philadelphia & Reading Railroad Co. Mr. Wister became a member of the Institute in 1898.

Thomas Woolston Yardley was born April 23, 1826, near Newtown, Bucks County, Pa., and received his business training in the dry-goods store of A. T. Stewart, New York. At the age of 25 he formed a partnership with his father in the iron commission-business at Pottsville, Pa. Later, he acquired a controlling interest in the firm of John Burnish & Co., proprietors of the Pottsville rolling-mills, makers of iron rails, which was afterwards organized into the Pottsville Iron & Steel Co. In 1860 he built the rail-mill of the Elmira Iron Co. at Elmira, N. Y., and for some time successfully operated it. During the Civil War he served, with the rank of colonel, in the department of military railroads. During this time the Government decided to build a rail-mill at Chattanooga, Tenn., to re-roll the iron rails twisted and destroyed by the Confederates. The mill was constructed under Col. Yardley's direction and

equipped with machinery designed and built by John Fritz, and had been in operation only a short time when peace was declared. It was subsequently purchased by the Southwestern Iron Co. Col. Yardley then accompanied Col. W. W. Wright in the survey of the Kansas Pacific R. R., acting as geologist. After various temporary employments he moved to Troy, N. Y., and became purchasing-agent with the Albany & Rensselaer Iron and Steel Co. In 1888 he resigned this position to take part in the firm of R. W. Hunt & Co., Chicago, and retained charge of the department of cast-iron pipe-inspection until his death, November 21, 1900. He became a member of the Institute in 1883.

The Secretary announced that the next meeting of the Institute would be held in Mexico, early in November, and that further details would be sent to members by circular hereafter.

After the formal presentation of sundry other papers (see lists below), the meeting was adjourned.

An informal session was held Friday evening, February 22, at 9 o'clock. Mr. Theodore Dwight exhibited a number of lantern views from photographs recently taken by him in Mexico, during a recent visit in connection with preparations for the Mexican meeting of the Institute in November.

PAPERS PRESENTED IN PRINTED FORM AND NOT INCLUDED ABOVE.

Concentrating-Tests and Calculations, by Otto F. Pfordte, Rutherford, N. J.

The Forecast of Chemical Reactions from the Algebraic Signs of the Quantities of Heat Liberated, by H. Le Chatelier, Paris, France.

Note on Cheap Gold-Milling in Mexico, by Henry F. Collins, Mina de Santa Fe, Mexico.

PAPERS PRESENTED IN MANUSCRIPT, OR READ BY TITLE, FOR SUBSEQUENT PUBLICATION AND DISCUSSION.

Biographical Notice of James W. Tyson, by William Glenn, Baltimore, Md.

Biographical Notice of Samson Jordan, by R. W. Raymond, N. Y. City.

Gold-Mining in the Transvaal, South Africa, by John Hays Hammond, Denver, Colo.

Coal-Fields of Northeastern China, by N. F. Drake, Tientsin, China.

Investigations of Magnetic Fields With Reference to Magnetic Ore-Concentration, by Walter R. Crane, Lawrence, Kan.

The Missouri and Arkansas Zinc-Mines at the Close of 1900, by Eric Hedburg, Joplin, Mo.

Problems in Hauling and Hoisting, by Alexander Bowie, Gallup, New Mexico.

The De Lamar and Horn-Silver Mines: Two Types of Ore-Deposits in the Deserts of Nevada and Utah, by S. F. Emmons, Washington, D. C.

A Study of the Effect of Heat-Treatment on Crucible-Steel Containing One Per Cent. of Carbon, by George William Sargent, Reading, Pa.

Note on the Geology of Southeastern Arizona, by E. T. Dumble, Guaymas, Sonora, Mexico.

The Use of the Triaxial Diagram in the Calculations of Slags, by Ernest A. Hersam, Berkeley, Cal.

Some Recently Exploited Wolframite Deposits in the Black Hills of South Dakota, by John D. Irving, Washington, D. C.

Chromite as a Hearth-Lining for a Crucible Smelting Copper-Ore, by William Glenn, Baltimore, Md.

The Constitution of Cast-Iron, with Remarks on Current Opinions Concerning It, by H. M. Howe, N. Y. City.

The Formation of Bonanzas in the Upper Portions of Gold-Veins, by T. A. Rickard, Denver, Colo.

A Rapid Assay for Silver and Gold in Metallic Copper, by George L. Heath, South Lake Linden, Mich.

Notes on Tripod-Heads, with Reference to Mr. Dunbar D. Scott's Paper on the Evolution of Mine-Surveying Instruments, by John H. Hardens, Phœnixville, Pa.

Members and Associates Elected.

No *viva voce* election of members or associates was held at this meeting. The following list contains the names of persons elected members or associates by postal ballot of November, 1900, and January, 1901.

Members.

W. C. Agnew, ...	Duluth, Minn.
William Pope Anderson, . .	Ouray, Colo.
George H. Arlett, . . .	Santa Rita, N. M.

Henry H. Armstead, . .	New York, N. Y.
Ernest P. Ashmore, . . .	Chile, Venezuela, S. A.
Chester S. Batchelder, . .	Spokane, Wash.
James H. Batcheller, . .	Lead City, S. D.
Hans C. Behr, ...	Johannesburg, So. Africa.
Frederic V. Bodfish, . .	Victor, Colo.
G. Melville Boynton, . .	Coaldale, Hayden Creek, Colo.
C. T. Brown, ...	Socorro, N. M.
Luke W. Bryan, . . .	Alderson, Indian Ter.
Albert Burch, ...	Kellogg, Idaho.
William H. Burrage, . .	Santa Rita, N. M.
Nathaniel A. Carle, . . .	Sherbrooke, Quebec, Canada.
William E. Carroll, . . .	Mancelona, Mich.
M. D. Chapman, . . .	New York, N. Y.
John Chisholm, . . .	Kalgoorlie, W. Australia.
Roy H. Clarke, . . .	Rossland, B. C., Canada.
Harry Colbath, . . .	Bingham Cañon, Utah.
Horace F. Collins, . . .	Barroteran, Coahuila, Mexico.
Charles W. Comstock, . .	Lawrence, Kan.
Thomas Cox, ...	Mullan, Idaho.
Walter R. Crane, . . .	Lawrence, Kan.
Thomas B. Crow, . . .	Idaho Springs, Colo.
William B. Daniel, . . .	Webb City, Mo.
Edward H. Davies, . . .	London, England.
William H. Day, Jr., . .	Dubuque, Iowa.
Heber Denman, . . .	Alderson, Indian Ter.
Robert N. Diggles, . . .	Nevada City, Cal.
John Van N. Dorr, . . .	Florence, Colo.
Robert M. Draper, . . .	Great Falls, Mont.
Howard N. Eavenson, . .	Uniontown, Pa.
Arthur J. Edwards, . . .	Minneapolis, Minn.
Louis V. Emanuel, . . .	Barranca del Cobre, Mexico.
S. G. Evans, ...	Joplin, Mo.
Edward N. Fell, . . .	Nelson, B. C., Canada.
Frederick M. Field, . . .	Pony, Mont.
Randolph E. Fishburn, . .	Chicago, Ill.
J. H. Fisk, ...	Portland, Ore.
Edward L. French, . . .	Syracuse, N. Y.
Franz Germann, . . .	Oruro, Bolivia, So. America.
Allan Gibb, ...	Liverpool, England.
W. H. H. Ginder, . . .	Vandergrift, Pa.
H. H. Godshall, . . .	Lansdale, Pa.
Lawrence W. Grayson, . .	Broken Hill, New So. Wales.
Harry A. Guess, . . .	Keewatin, Ont., Canada.
Lafayette Hanchett, . . .	Idaho Springs, Colo.
Dana Harmon, ...	Gaston Ridge, Cal.
E. Heneage, ...	London, England.
Walter H. Hill, . . .	Grangeville, Idaho.
Lucius L. Hubbard, . . .	Houghton, Mich.
Robert G. Hutchins, Jr., . .	Columbus, O.
Victor Hybinette, . . .	Bayonne, N. J.
Daniel C. Jackling, . . .	Republic, Wash.

E. Fleming Lengle, . . .	New York, N. Y.
John S. Loder, ...	Leadville, Colo.
A. C. Luck, ...	Austin, Nev.
Robert Lyman, Jr., . . .	Rossland, B. C., Canada.
Allan E. McCulloch, . .	Chañaral, Chile, So. America.
Joseph A. McDonald, . .	Youngstown, O.
Jesse J. MacDonald, . .	Mexico City, Mexico.
John H. McLean, . . .	Ironwood, Mich.
Ernest A. Mannheim, . .	Gaudagai, New So. Wales.
Nicholas J. Martin, . . .	San Juancito, Honduras, C. America.
Henry A. Mather, . . .	New York, N. Y.
Juan Maurice, ...	Potosi, Bolivia, So. America.
William W. Mein, . . .	Oakland, Cal.
C. A. Meissner, . . .	Cape Breton, Nova Scotia.
Charles E. Morris, . . .	Pony, Mont.
Frank H. Morris, . . .	Bridgend, So. Wales, England.
H. H. Muggley, . . .	Galena, S. D.
Charles S. Newhall, . . .	Bruce Mines, Ont., Canada.
George A. Nicholls, . . .	Deadwood, S. D.
Keijiro Nishio, ...	Hokkaido, Japan.
Thomas Noon, ...	Deadwood, S. D.
John P. O'Neill, . . .	Butte, Mont.
Ezequiel Ordonez, . . .	Mexico City, Mexico.
Samuel W. Osgood, Jr., . .	Crystal Falls, Mich.
Frank D. Pagliuchi, . . .	El Cobre, Santiago de Cuba, Cuba.
Walter J. Pentland, . . .	Concheno, Chihuahua, Mexico.
Francis L. Piddington, . .	Dapto, New So. Wales.
Louis W. Powell, . . .	Duluth, Minn.
Jasper R. Rand, . . .	New York, N. Y.
Frederic L. Ransome, . .	Washington, D. C.
David C. Reed, . . .	New York, N. Y.
David Rees, ...	Wardner, Idaho.
Ferdinand H. Regel, . .	Sombrerete, Zacatecas, Mexico.
John F. Rice, ...	Spokane, Wash.
Horace P. Robertson, . .	Kalgoorlie, W. Australia.
Leverett S. Ropes, . . .	Combermere, Ont., Canada.
Edwin P. Ryan, . . .	Houghton, Mich.
Nicholas Samwell, . . .	North Celebes, Dutch E. Indies.
Charles E. Schaup, . . .	Philippi, W. Va.
Albert E. Seal, ...	Nottingham, England.
Solon Shedd, ...	Pullman, Wash.
William J. Sherwood, . .	Marysville, Mont.
Alphonse Sinn, ...	Valparaiso, Chile, So. America.
Amos Slater, ...	Arasta, Cal.
Edward C. Small, . . .	Salt Lake City, Utah.
Henry V. Snell, . . .	Rossland, B. C., Canada.
Harrison Souder, . . .	Philadelphia, Pa.
Jacob J. Sperry, . . .	Welch, W. Va.
Josiah E. Spurr, . . .	Washington, D. C.
Otis T. Stantial, . . .	Chicago, Ill.
Francis B. Stephens, . .	Dunedin, New Zealand.
Edmund de Stoutz, . . .	Geneva, Switzerland.

Guy C. Stumm, . . .	Denver, Colo.
Robert M. W. Swan, . .	Kuala Lipis, Pahang, Malay Peninsula.
Albert W. Taylor, . . .	Chitobalbie, Korea.
Harry P. Townsend, . . .	Port Elizabeth, Cape Colony, So. Africa.
Henry W. Turner, . . .	Washington, D. C.
Abraham Van Zwaluwenburg, .	New York, N. Y.
Carl Vogelsang, . . .	London, England.
John L. Wagner, . . .	Columbus, O.
W. L. Wrightson, . . .	Northumberland, England.
Lawrence F. J. Wrinkle, . .	Reno, Nev.
Yang Tsang Woo, . . .	Tientsin, China.
George J. Young, . . .	Reno, Nev.

Associates.

William B. Barber, . . .	Alameda, Cal.
Rupert H. Bradburn, . .	Peterboro', Ont., Canada.
Sterling B. Cox, . . .	Buffalo, N. Y.
Ivan De Lashmutt, . . .	Berkeley, Cal.
Wheeler S. Edwards, . .	Franklin Furnace, N. J.
Charles V. Jenkins, . . .	Rossland, B. C., Canada.

Associates made Members.

Milo W. Krejci, . . .	Great Falls, Mont.
T. D. Rand, ...	Philadelphia, Pa.
Augustus Simson, . . .	Launceston, Tasmania.
Lester Strauss, ...	New York, N. Y.

Excursions and Entertainments.

On Wednesday afternoon a large party visited the new installation of the Virginia Electrical Railway and Development Co., inspecting the masonry dam 1700 ft. long, across the James, and the power-house with auxiliary steam-machinery, supplementing the water-power.

A visit was also made to the tobacco-factory of the T. C. Williams Co., where between 500 and 600 operators (principally colored) are employed. A chorus of operators entertained the visitors with characteristic songs.

In the evening a reception was given, in the court and parlors of the Jefferson Hotel, by citizens and ladies of Richmond.

On Thursday afternoon, excursions were made to the W. R. Trigg shipyards, the Richmond Locomotive Works, and the Richmond Chemical Works of the Virginia-Carolina Chemical Co., situated on the north bank of the James. This establishment has a producing-capacity of 500 tons of fertilizers daily. The crude phosphate-rock is crushed and treated with sulphuric acid, of which the works can produce (by roasting pyritic ores)

400 tons per week. The ores are the "fines" from the Co.'s mines in Louisa co., Va., and are roasted in Spence furnaces or Hand shelf-furnaces—both types being in use. The plant includes Glover and Gay-Lussac towers, lead-chambers, etc.; is lighted with electricity; and employs in the busy season about 300 men, receiving and shipping from 20 to 30 car-loads of material daily. The dock-arrangement permits, by means of the Hunt cable-system, the discharge of a steamer-cargo upon two docks at once, and similar rapid loading of the vessel.

On Thursday evening a subscription-banquet was held at the Jefferson Hotel. About 130 ladies and gentlemen were present; and speeches were made after dinner by Gov. J. Hoge Tyler, of Va., and other representatives of the State and city, and by the past-president and the president elect of the Institute, etc.

On Friday morning, a special train, tendered by the Chesapeake & Ohio Railway, conveyed a large party to the University of Virginia at Charlottesville. About 25 persons left this train at Mineral City, taking another train for the pyrite-mines, where they were hospitably entertained. A considerable number of the Charlottesville party were driven to Monticello, once the beautiful residence of Thomas Jefferson, now the place of his tomb.

At the University of Virginia, the visitors were courteously received by its officers, and enjoyed greatly the inspection of its historic campus, and the effective architectural grouping of its buildings, originally planned by Jefferson, and recently extended in accordance with his plan. The new buildings for Physics and Engineering were viewed with special interest.

Members, Associates and Guests Registered.

The following persons were registered at headquarters:

Taylor Allerdice.
James Archbald.
John Birkinbine.
W. H. Blauvelt.
Alfred H. Brooks.
Henry W. Bulkley.
T. M. Chatard.
W. B. Cogswell.
Edgar S. Cook.
George Gordon Crawford.
David T. Day.
James Douglas.
F. R. Dravo.
Theodore Dwight.
S. F. Emmons.
Thomas M. Eynon.
B. F. Fackenthal, Jr.
Herbert Flournoy.
Henry Froehling.
J. M. Garvin.
Claude L. Gaujot.
Ware B. Gay.
Paul Glazenapp.
William Glenn.

C. W. Hayes.
Rowland F. Hill, Jr.
Levi Holbrook.
W. S. Hungerford.
Robert W. Hunt.
W. J. Johnston.
W. R. Johnston.
Clemens Catesby Jones.
Thomas Catesby Jones.
James F. Kemp.
W. S. Kimball.
Morris K. King.
Paul S. King.
Charles Kirchhoff.
Edward K. Landis.
Benjamin B. Lawrence.
A. R. Ledoux.
J. H. Lee.
J. F. Lewis.
Waldemar Lindgren.
Stuart Lindsley.
Burdett Loomis.
J. H. Loomis.
W. B. Middleton.
George S. Morison.
Henry G. Morris.
E. E. Olcott.
George D. Ormrod.
E. W. Parker.
Edmund C. Pechin.
C. P. Perin.
S. M. Pitman.
Henry W. Potts.
Alfred Raymond.
R. W. Raymond.
V. A. Rhodes.
Ellen H. Richards.
R. H. Richards.
R. P. Rothwell.
Edward H. Sanborn.
A. W. Sheafer.
J. M. Sherrerd.
J. William Smith.
E. S. Sperry.
E. Gybbon Spilsbury.
A. Thies.
Wm. H. Van Arsdale.
Wm. R. Webster.
Wm. H. Wiley.
John Wilkes.
F. W. C. Whyte.
N. A. Woodbury.
J. B. Woodworth.

This list does not include the ladies accompanying members, whose names would increase the total to 124.

PAPERS.

Biographical Notice of Thomas Egleston, Ph.D., LL.D.

BY GEORGE F. KUNZ, NEW YORK CITY.

(Washington Meeting, February, 1900.)

It is with a mournful pleasure, and at the same time with a profound consciousness of my inability to present in brief compass an adequate account of such a life and character, that I undertake, at the request of the Council, the task of preparing a memorial sketch of our eminent associate and friend, the late Prof. Thomas Egleston, one of the original members of the Institute; a member of its first Council in 1871; by repeated elections one of its Vice-Presidents for terms aggregating seven years; in 1887 its President; and for many years an active and valued contributor to its *Transactions*.*

Moreover, his death has deprived New York of a citizen who united refined culture and professional eminence with high ideals of civic responsibility and duty; the Christian church has lost a member zealous and intelligent in benevolent works; and America mourns a scientist, honored on both sides of the Atlantic, who has left an abiding impress upon the scientific progress of this nation.

In the last aspect, Prof. Egleston achieved a memorable work in two related lines—first, through his co-operation in the establishment of this Institute and his contributions to its *Transactions*; and secondly, in the planning, founding and organizing of the School of Mines of Columbia College in New York. But besides these, there were in his life many interesting and noble features, upon which I can but briefly touch in this sketch.

---

* In preparing this sketch, I have made free use of two full and careful biographical notices of Prof. Egleston: one published before his death in the *Popular Science Monthly* for June, 1899, by his friend of many years, Prof. Daniel S. Martin; the other contributed to the *School of Mines Quarterly* for April, 1900, by his pupil, assistant and successor in the school, Prof. Alfred J. Moses. Since it would be impossible to indicate by quotation-marks the material appropriated, from these sources, I trust this frank acknowledgment of my debt will be accepted as sufficient.

Thomas Egleston came of New England stock. His ancestors were among the first settlers of Dorchester, Mass., in 1635. Thence, by a toilsome and perilous journey, they migrated to Connecticut, and founded the town of Windsor, which was thenceforward their home, until Thomas Egleston, the father, came to New York, where our friend was born, December 9, 1832. Here he lived and labored to the end, though traveling far and wide in the course of his scientific work; and here he should be remembered and honored.

As a boy he took considerable interest in certain branches of science, and at the age of thirteen had gathered a collection of minerals and rocks. He attended Yale College; and, in the later years of his course, took special elective work in chemistry. After graduation in 1854, he was for a time an assistant to Prof. Benjamin Silliman, Jr. Subsequently he went abroad, partly for his health, and was advised to spend some time in Paris. With no special professional purpose, but from a general desire to improve his time, he began attending lectures on geology and chemistry in the *Jardin des Plantes*, under D'Orbigny (a brother of the eminent writer) and Hilgard, and worked with much energy in the laboratories of these departments at the *Jardin*. He thus attracted the attention of some of the faculty of the *École des Mines*, who offered him larger facilities in that institution, which he at once accepted. After much interesting study in the paleontological laboratory there, he decided to go through the entire course, and accomplished that purpose with notable success and honor in 1860. He had worked as an assistant in every laboratory of the school, and in the summers had traveled through much of France, becoming familiar with its geology, mineral resources, mining works and processes, and gaining a mastery at first-hand of all branches of these subjects. Those years were to him full of interest and enjoyment; friendships were formed which enriched his whole life; and in it all he was being prepared for the work of developing the corresponding forms of science and of industrial progress in our own country. Prof. Egleston always retained toward the *École des Mines* a strong feeling of attachment, which was warmly reciprocated; and he showed his interest by two gifts to the institution of five thousand dollars each.

After a year or more spent in travel, Dr. Egleston returned to New York in 1861, and was almost immediately called to Washington to take charge of the work of sorting, determining and arranging the specimens which had accumulated at the Smithsonian Institution from the numerous governmental exploring expeditions. Of these he prepared a series for the Institution, using the duplicates to inaugurate a system of international exchanges. In connection with this work he prepared his first publication—a "Check List and Catalogue of Minerals," which was widely distributed.

That this work was well done, is evidenced by the fact that for eight years after the starting of the School of Mines, the undistributed duplicates, and all later accessions to the Smithsonian Institution collection, were forwarded to Prof. Egleston under an arrangement by which he was "to select and label a perfect single series for the National Museum, and to exchange the duplicate specimens in its interest."

This work at the Smithsonian, in connection with his previous studies abroad, led him to recognize both the need and the opportunity for an institution that should occupy a position in this country somewhat like that of the *École des Mines* in France.

At that time, there were in America a few schools of science, well organized and well equipped—the Sheffield School at Yale; the Lawrence foundation at Harvard; the Rensselaer Polytechnic Institute at Troy, and others;—but their scope was either too general or too special to include distinct and adequate training in mining and metallurgy.

In March, 1863, Dr. Egleston published a "Proposed Plan for a School of Mines and Metallurgy in New York City," in which, in a modest little outline of some 1500 words, he stated the object of the school, the proposed course of instruction, and the estimated cost for a first equipment—about $30,000.

The purpose, as given in his own words, was "to furnish to the student the means of acquiring a thorough scientific and practical knowledge of those branches of science which relate to mining and the working up of the mineral resources of this country, and to supply to those engaged in mining and metallurgical operations, persons competent to take charge of new or old works, and conduct them on thoroughly scientific principles."

This was a new departure in American education. Some suggestions and attempts had been made before in this direction, but the time had not been ripe. Meanwhile, reckless and incompetent methods prevailed in our mining operations, leading to much waste and consequent failure, while even those enterprises which were financially profitable were conducted at great disadvantage.

But now, "the hour had come, and the man." Dr. Egleston's idea appears to have been to graft a school upon some existing institution; and fortunately he submitted the plan to the Trustees of Columbia College, who had been considering for several years the establishment of schools for post-graduate work. The opportunity for a first step in this direction seemed to be presented in the plan of Dr. Egleston; for it was proposed to pay all the expenses of the school from fees. The scheme was taken up with interest by certain leading trustees of the college, especially by the late George T. Strong. The President also, the late Dr. Charles King, and a majority of the Board, favored the experiment, and arrangements were finally made to begin it in the autumn of the next year, in limited quarters in the old college building on 49th St., with provision for not more than 20 students. Part of the instruction was to be given by members of the existing college faculty; and three new professors were appointed to special chairs in the school, to be compensated by fees therefrom. These were, Professor Egleston for mineralogy and metallurgy; General Francis L. Vinton, one of his friends and classmates in Paris, for mining engineering; and Dr. C. F. Chandler, then of Union College at Schenectady, N. Y., for chemistry.

Meanwhile, in June, 1864, President King was succeeded by the late Dr. F. A. P. Barnard, whose strong interest in science made him a warm supporter of the school. Already some eminent persons, impressed with the value of such a movement, were disposed to aid it. A fine collection of minerals was purchased and presented by Mr. Strong, and another was given by Mr. Gouverneur Kemble.

On the opening day, Nov. 15, 1864, the number of applicants was far beyond expectation or accommodation. The School was found to respond to a need and a demand that had not been suspected. It was a success from the first. In a year or two it

had become an institution of recognized importance; ample quarters were provided for it in a large building, formerly a manufactory, on the Fourth avenue side of the college-block; and important additions were made to the corps of instructors, particularly the eminent geologist, Dr. J. S. Newberry, of Cleveland, Ohio, whose splendid geological collection was deposited for use in the School of Mines, and whose breadth of knowledge, intellectual power and personal magnetism profoundly influenced scientific interest and progress in the city of New York for more than twenty years.

In the earlier and formative years of the institution, Prof. Egleston was the central and leading spirit. His time, thought and labor were given to it with unwearied enthusiasm. As the school grew under his guidance and overran the possibility of this intense personal supervision, his work became more limited to his own special departments; but he loved to look back to those earlier years of his first enthusiasm and "all around" activity, and spoke of them as "halcyon days."

His special departments, as I have said, were mineralogy and metallurgy. It is in the latter of these that he was probably best known to the members of the Institute; but his eminence in metallurgy and in the related field of mining engineering was attained rather as the result of circumstances than of choice. His first love was mineralogy; and he would have made that his peculiar and principal line of work, had he not been forced to take the chair of metallurgy also, from the lack of a competent occupant for it in the earlier years of the School of Mines.

Prof. Egleston's work in the building up of the great mineralogical collection of the School was a remarkable achievement.

Prof. Moses, his pupil and successor, says that the story of the creation of the present mineral collection of 30,000 specimens is one that cannot easily be paralleled in collection-building. There has been no fund for the purchase of minerals, and at no time a curator. Most of the specimens have been secured either by gift or by exchange for others similarly obtained. The 30,000 specimens now there represent the picked residue of at least 100,000 acquired and exchanged.

Columbia College had, at the outset, a cabinet of about 3000

specimens, one-third of which had belonged to Dr. Moore, President of the College from 1842 to 1849, and well known as the author of Moore's "Ancient Mineralogy." To these were added the two collections already mentioned as presented to the new school in 1864 by Messrs. George T. Strong and Gouverneur Kemble. Soon after, Prof. Egleston effected an arrangement with the Smithsonian Institution, by which he obtained for the School of Mines important opportunities of acquisition through foreign exchanges. From this time, gifts and exchanges went on rapidly; and the collection became rich and extensive. Foreign governments and mines presented important sets of specimens; and liberal friends of science contributed valuable additions; while constant gains were made through the students and graduates of the School itself, in their travels, studies and collections from year to year. At the same time and in the same ways the library was enlarged and enriched with publications relating to minerals and mining.

From the very beginning, when this noble collection was yet in its earliest stages, Prof. Egleston looked forward to what it should become, and planned and prepared for it accordingly. His own special interest lay in the two departments of crystallography and optical mineralogy. He began at once the illustration of the collection with a series of wooden models, arranged in the cases with the specimens, showing for each species, side by side with the mineral itself, its principal forms of crystallization, both general and peculiar. Of the preparation of these models, the following account is given by Prof. A. H. Chester, of Rutgers College, N. J., who was Prof. Egleston's first assistant:*

"The making up of a collection of crystal models in wood, for use in teaching crystallography, was a great work, and took up the time of nearly a whole college-year. This set of models was by far the most complete that had been seen in this country up to that time, and was admirably adapted for the purpose intended. Professor Egleston was most interested in this collection, and was continually calling for the construction of additional forms, and bringing books from his library to help in the work. As new and seldom-seen forms were made, he showed a keen delight in them, and never seemed to tire of looking at them and talking about them. His interest and enthusiasm were so great as to completely absorb him, and I recall those months as among the most pleasant during my years of intercourse with him."

* *School of Mines Quarterly*, vol. xxi., No. 3, April, 1900, p. 206.

His enthusiasm for optical mineralogy assumed, in the early years of the School, a like prophetic aspect.

Prof. H. B. Cornwall, of Princeton University, who, as his second assistant, succeeded Prof. Chester, writes as follows in regard to this department. After referring to the rapid growth of the School during the first five years, and its transfer to enlarged quarters, describing the intense and constant activity of Prof. Egleston in studying and examining the new material constantly coming in, lecturing and holding conferences with his students, revising proofs, testing and improving apparatus, etc., he goes on to say:*

> "Nor was the practical side the only one that attracted him. A great deal of energy was spent on what I know his colleagues considered the too theoretical side of mineralogy. He gathered apparatus for optical mineralogy; and, although he did not lecture on it during my time, yet he had mechanics and opticians busy much of the time in devising new arrangements of apparatus, which . . . he hoped some time to bring into use. The result of his initiatory work is now . . . seen in the fine equipment at Columbia for this sort of study."

The last great addition to the collection was Prof. Egleston's final gift to it of his own rich and remarkable private cabinet, of some 6000 or 7000 specimens, which he presented to the School a few months before his death. This cabinet was largely selected with special reference to his favorite branch of crystallography. With it he also gave his whole scientific library. There is something beautifully appropriate, and even pathetic, in this closing gift to what had been so remarkable and successful an enterprise—so great a delight in his years of activity and so noble a monument to his name and his memory.

On February 5, 1900, a few weeks after his death, the Trustees of Columbia University performed a most fitting act in attaching his name to the mineralogical collection of the institution. It will, as it should, remain his permanent memorial as the "Egleston Mineralogical Museum."

This museum, situated as it is in the city of New York, the metropolis of the country, and adjacent to one of the largest scientific libraries in the United States, could, with no great sum as an endowment, be made of immense value to the mining

* *Id.*, p. 208.

engineers, chemists, geologists, and others, who not only wish to refer to the literature of the subject, but who desire to examine mineralogical specimens and their associations, the collections and the library interests.

Prof. A. J. Moses, the present incumbent of the chair of mineralogy founded for Prof. Egleston and held by him until Prof. Moses took it, informs me:

(*a*) That the collection comprises 30,000 specimens; a library of 750 books and 2500 pamphlets, and a card-catalogue of about 20,000 references, in addition to apparatus, models, sections, etc., more correctly forming a Department than a Museum.

(*b*) That the work of the museum has hitherto been done by the officers of the institution, but that in the last ten years the number of students taking mineralogy has doubled, and the hours required for instruction have been necessarily increased 50 per cent., without any enlargement in the force, thus greatly reducing the time available for museum-work.

(*c*) That, with clerical assistance, the available time of the officers might be given to the kind of work that would tend to make the museum famous.

(*d*) That with an endowment, the museum could be made a standard reference-collection, representing all species, varieties and localities; and also that other special collections could be developed; whereas, without such aid, only irregular development is possible from casual gifts or any small unexpended balance from the departmental appropriation. This balance, last year, was only about $70.

It is surely a matter of interest and importance that so great a treasure-house of science as this should receive the utmost facilities of enlarged usefulness, and become the center of reference and study, not only for the institution, of which it already forms a part, but for the mining engineers of the country.

With Prof. Egleston's work in metallurgy most of the members of this body are already familiar. When the School was opened, and for some years afterward, he was constrained to occupy the chair of metallurgy jointly with that of mineralogy, which, as I have said, would have been his own special choice.

The formation of this Institute in 1871 gave a great impetus to his work in metallurgy, and affected his further studies and publications. He was elected a member at the first meeting,

and for twenty years was active and prominent in the work of the Institute. He was twice Manager; three times Vice-President, and was President in 1886–7. Over thirty articles were contributed by him to the *Transactions;* while his total publications on metallurgical and kindred topics reached the number of nearly one hundred. Much of this exceedingly varied material was the result of data gathered in his many trips abroad, or in four extensive tours to our own West. In regard to these articles, his friend and fellow-member, Dr. R. W. Raymond, has said:*

> "His numerous contributions to the *Transactions* of that Society (Am. Inst. Min. Engrs.), extending through many years, present this common feature: that all of them are, to a striking degree, timely and suggestive, though few, perhaps, could claim to be exhaustive and conclusive. In other words, Dr. Egleston, in his constant survey of a wide range of professional topics, had the faculty of recognizing those which possessed immediate critical importance; and with regard to these, he contributed to the common stock of information, without pedantic conceit or futile delay, whatever knowledge he had acquired, whether by personal investigation or by observation or compilation."

At the outset of his work in the School of Mines, and largely to the end, Prof. Egleston's work was by lectures. At first this was inevitable, as there were hardly any available textbooks, either printed in English or adapted for use in America. These lectures he supplemented by a very strict system of examination of students' notes, and by the requirement of a summer tour of observation and study to some point or region of scientific importance, of which a formal report was to be prepared and presented in the autumn. Each student received a personal letter of directions from Prof. Egleston as to the points to be visited and the special studies to be made.

These methods soon bore fruit. The School attracted notice from the first, abroad as well as throughout this country. In 1871, seven years from its opening, a writer in the *North American Review* characterized it as "already more scientific than Freiberg; more practical than Paris," and emphasized its influence both upon science and mining interests in the United States, pointing out that the literature pertaining to mines and their working had been very limited in the English language, and that the instruction in the School had to be chiefly given

---

* *Id.*, p. 213.

by lectures; but that these courses would gradually develop into a literature.

These suggestions have been fully justified by the results of the last quarter-century. The vast development of our mineral resources has been largely directed by graduates of this School. Hundreds of them are to-day in important positions of scientific trust, not only throughout our own country, but in South and Central America, Australia, China, Japan and Europe. The lectures of the professors and the articles constantly published in the *School of Mines Quarterly* have given us a literature of the subject in English. The local influence in the city has been great upon scientific education in secondary schools and upon general public sentiment; while, in Columbia University, the experiment has become one of its finest departments and an element of the greatest strength. Rarely is it given to a man to see in his lifetime so momentous a result from the plans and labors of his earlier years.

But these successful labors were but a part of Prof. Egleston's manifold activities. In 1866 he was associated with the agricultural and geological survey of the first hundred miles of the Union Pacific Railroad. In 1868 he was appointed a United States Commissioner to examine the fortifications of the coast. In 1873 he was a juror at the Vienna Exposition. He was one of the organizers of the American Institute of Electrical Engineers, the Society of Mechanical Engineers and the American Metrological Society, and a member of the Society of Civil Engineers, the Iron and Steel Institute of Great Britain, the New York Academy of Sciences, the Century Association, and many other similar bodies. As a member of the Committee on Standardization appointed by the American Society of Civil Engineers he favored a millimeter wire-gauge standard in opposition to other members, who favored a scale in thousandths of an inch.

Prof. Egleston retained throughout his life a very warm interest in the *École des Mines* at Paris, and kept up close relations with it and with French scientists in many ways that were highly appreciated. In this regard he did a peculiar work, which was naturally but little known in this country. Most American students who go abroad study in the institutions of Germany, and form their associations there. But

Prof. Egleston felt that it was to the institutions and the scientists of France that he owed his career, and that all his high attainments, his cherished memories and his training for the great work that he accomplished here were associated with the men and the methods of the *École des Mines.* This feeling never left him; and his sense of attachment and of gratitude impelled him to render many important services both to the institution itself and to scientists from France that no other American could have done.

At considerable expense he completed the imperfect sets of geological reports of our different States contained in the library of the *École des Mines.* This in itself was no small service. He presented to the library all his own publications and many others, which have been largely used and quoted in subsequent works on metallurgy issued in France. He gave many rare and valuable minerals to their cabinet, and secured for it also the gift of important sets of specimens exhibited by Americans at the Paris Exposition of 1867, where he was in charge of the entire United States mineral collections. In addition to these services, he was a constant and liberal source of information in regard to mineral production and metallurgical processes in this country, to professors, graduates and students of the School, who used to write to him for all such data. Through him, also, various scientific bodies and collectors in other parts of France were able to arrange facilities for the exchange of specimens and books. He rendered similar services to the library of the French School of Bridges and Roads, completing their sets of our State Geological Reports, and the very important series of reports of the United States Coast Survey.

To French scientists visiting this country, Prof. Egleston was equally helpful and liberal. Mining engineers, civil engineers, and representatives of the School of Bridges and Roads all could, and did, obtain from him maps, advice, and information as to important points of interest, and letters of introduction all over the country. At the Centennial Exposition at Philadelphia, in 1876, he was on the Committee of Reception for foreign engineers, and made the French visitors his especial care. In the same way he was the adviser and helper of several commissions sent to America by the French government,

for the collection of statistics and material relating to our oil-production and other mineral industries.

Nor was his service limited to the scientific field. He was always interested in aiding and counseling French people, both men and women, who found themselves in distress or necessity here in a strange land. His connection with the Smithsonian Institution, at the very outset of his professional career, was during the early part of our Civil War, and he gave much time and attention to the Frenchmen among the sick and wounded in the hospitals at and near Washington, visiting them and conversing with them, and looking after cases of special need.

His work in the N. Y. Academy of Sciences was active and influential through many years. He was its Vice-President from 1869 to 1881; and when the old and honored name which the society had borne from its organization in 1818—the New York Lyceum of Natural History—was changed to that of the Academy of Sciences, in 1876, in order to broaden its scope, Prof. Egleston was the officer upon whom was laid the very careful and responsible task of revising and remodeling the entire constitution and by-laws. To this work he gave a great deal of time and thought, in connection with his associate on the committee, Prof. D. S. Martin; and the work thus done proved exceedingly successful, and has stood the test of a quarter of a century with scarcely a recognized defect.

Of his publications, the list of his nearly a hundred books, pamphlets and articles can alone give a full idea of Prof. Egleston's ceaseless and many-sided literary activity in his favorite lines of professional work. Almost every topic connected with metallurgy and mining engineering, and many related subjects—mineralogical, crystallographic, economic—have been dealt with by his ready pen. More than thirty of these articles appeared in the *Transactions* of this Institute; more than twenty in the *School of Mines Quarterly*; several in the *Annals* of the Academy of Sciences and in the proceedings of the societies of Civil and of Mechanical Engineers; while a long series in London *Engineering* became later the basis of his most ambitious work, "The Metallurgy of Silver, Gold and Mercury in the United States," published in two large volumes in 1887 and 1890.

But his professional record is far from being the record of

his life-work. Although devoted to his own special departments of study and research in mineralogy, metallurgy and mining engineering, Prof. Egleston was a man of great breadth of scientific interest and of large public spirit. Two very notable illustrations of these qualities were given in his successful efforts for the erection of the monument to Audubon, and for the preservation of Washington Square. No notice of his life would be complete which did not make some reference to these important episodes.

Audubon, the great artist-ornithologist, had been buried in 1851, near his suburban home in the upper part of Manhattan Island, in a family vault, in a secluded part of Trinity Cemetery, then far out of town, about a mile and a half beyond the present Morningside Park. When 153d St. was to be opened to the river, the vault, close to the street-line, was in danger of injury. Prof. Egleston took up the matter, and proposed the removal of the remains to another part of the ground, and the erection of a suitable monument. The plan was adopted by the New York Academy of Sciences in the autumn of 1887, and a committee was chosen, with Prof. Egleston as Chairman, to endeavor to raise $10,000 for this purpose. After long delays and many discouragements, the result was attained, through the untiring devotion of Prof. Egleston, supported by the other members of the committee—Dr. N. L. Britton and Prof. Daniel S. Martin. The monument itself, designed by Prof. Egleston—a Runic cross, sculptured with American animals and birds—is a remarkable combination of the scientific, artistic and religious elements appropriate to the memory of Audubon—the nature-lover, the artist, and the Christian believer. As it stands to-day, over the grave of him whom it commemorates, it is an honor to the city and a fitting tribute to the great ornithologist. For this beautiful thought, so nobly carried out, American science and the City of New York are indebted to Thomas Egleston.

His public service in saving Washington Square from the devices of vandal speculators and politicians, is an almost unknown and unrecorded chapter in the history of the city. Under the notorious Tweed *régime*, a scheme was undertaken and nearly carried to completion that would have wrought a fate for Washington Square similar to that which had befallen

St. John's Park some years before. Under a variety of pretexts and false pretences of so-called "*improvement*," a bill was stealthily pushed nearly to passage at Albany, that would have given power to these underhanded schemers to enter upon their nefarious project. At a late day, and with great difficulty, in the face of all sorts of official denials, Prof. Egleston succeeded in discovering the true purpose of this bill and its promoters. In co-operation with a small circle of public-spirited citizens, he organized the body known as the "Public Parks Protective Association," of which he himself became the Secretary, and the late John Jay the President. With great energy and promptness, in the limited time that remained ere the bill should come up for passage, public attention was aroused by letters, circulars and the press. Protests and remonstrances were set on foot; the Academy of Medicine and the Academy of Sciences, and other similar societies, passed resolutions of remonstrance; and the result was the complete failure of the plot. Legislators were aroused, some to the real character of measures they had not fully understood, and others to the existence of a public sentiment upon which they had not counted; and the bill failed to pass. Nor was this all. A resolution was adopted, prepared by the association, guaranteeing the ground occupied by the square to be kept "*forever*," as a park for purposes of public health and recreation.

The suggestion has been made by Prof. Daniel S. Martin, a warm friend of Prof. Egleston's through many years, that a monument to his memory and his public services should be erected in Washington Square. There would be in this a fourfold fitness. Prof. Egleston was the man whose watchfulness, energy and public spirit saved that park to the people of New York; and surely that action alone deserves a permanent memorial. He was also a lifelong resident in the vicinity, and, during his later years, his home overlooked the square. Such a monument would, therefore, stand in full view of the house where his ripest years were spent. Again, in the same park is already erected a monument to another eminent engineer and member of this society, the late Alex. L. Holley, and there would be a bond of fitness and friendship in the erection near it of one to Prof. Egleston. Lastly, he was the prime mover and the tireless leader of the plan for a monument to the

naturalist, Audubon, as already described, and he himself should be likewise commemorated. New York owes it to herself as well as to his memory, that a man in whom public spirit and scientific attainment were so strikingly united, should thus be honored; and this society is the body, of all others, to take up this grateful task to perpetuate the memory of one of its most eminent founders.

Turning from his professional and his public services, I can refer only briefly to some more personal aspects of Prof. Egleston's career. He was a man of means, to whom the enjoyment of life was open, in the forms so eagerly sought by many, of ease and gratification. But he was too earnest to be ever satisfied with such an existence. He was too active intellectually and too serious morally to live for himself, or for the passing hour. He cared nothing for self-indulgence and little for fame. He never sought public notice or reputation; and he gave the whole energy of his life to high and honorable labors in the walks of science and to benevolent interest in behalf of the ignorant and needy. There are very few of whom so much can be said. Society would be far different, and the world far better, were there more such men.

Aside from his scientific work, Dr. Egleston gave a great deal of attention to religious and charitable interests. He was a vestryman of Trinity Church from 1878 to 1898, and at the time of his death he was Senior Warden and member of the Committee on Parish Work, Parish Schools and Cemetery. For nearly thirty years he was Vice-President of the Protestant Episcopal City Mission Society, and for some years a trustee of the General Theological Seminary. He also first introduced the "Food Kitchens" for the poor in New York. Aided and controlled more or less by Trinity corporation, though in different parts of the city, and in connection with different Episcopal churches, there are eight schools, with about one thousand pupils. In these are taught careful and scientific methods of training along modern lines, of eye and hand development, hygiene, economy and thrift, to children and youth of the neediest classes. Already for years much interested in these schools, Prof. Egleston, after his withdrawal from professional activity, gave much of his time to their advancement, and found intense gratification in observing the results of this training

among a class of children that, from their general environment, would grow up to be either a burden or a menace to the city. The intelligent culture of hand and eye, the mental quickening and moral uplifting, the capacity and purpose of honorable support, and the protection from moral and social perils imparted and secured through the agency of these schools were to him a constant source of enthusiasm.

In his home life, Prof. Egleston was exceedingly happy. He married Miss Augusta McVickar early in his professional career, and their life was one of ideal happiness for many years, until her death in 1895. This event was a great sorrow to him, especially as there were no children to be the stay of his solitary advancing years. In this connection, I may be pardoned for referring to one of the later incidents of Prof. Egleston's life, which is so beautiful and so characteristic that it cannot fail to be of interest.

During years of travel to and from many parts of Europe, Prof. Egleston had remarkable opportunities, in his visits to mining regions and his intercourse with mineralogists, to obtain fine and choice specimens of gems. These he had mounted in elegant forms as presents to his wife. After her death, the only satisfactory use to which this beautiful treasure of jewelry could be put seemed to him to be in the services of divine worship in the church. It is not possible in brief compass, without a figure, to describe the arrangement of these jewels on the base, stem and cup of the golden chalice, thus conceived and given by him to Trinity Church. It must suffice to say that there are one hundred and eighty stones inset, with embossed work, upon a cup and pedestal nine inches high and half that width. The species and varieties number fifteen, many of them in rare shades of color. Among them are the ruby-colored Siriam garnets, green "demantoid" garnets of the Ural ("Uralian emerald"), Ceylonese moonstones, colored diamonds, sapphires, both yellow and green (Oriental topaz and emerald), rubellites, red zircon, moldavite (the rare green obsidian of Moravia), green tourmaline, chrysoberyl, the rich purple amethysts of the Ural, etc. Considered either mineralogically or as a work of art, this chalice is almost unique; while the conception and design—which are wholly Prof. Egleston's own—reveal the same notable union of artistic and

scientific qualities that were shown in the Audubon monument before mentioned, joined with a religious and personal sentiment almost too sacred to be dwelt upon in a sketch like the present.

As I have already said, Prof. Egleston was a man who never courted fame or prominence. His studies, his work, his benevolent interests and his home-life with the partner he so loved and honored, were enough for his happiness, and filled to the full the measure of his energies and his desire. That he won honor and respect, however, it is needless to say.

In 1874 the degrees of Ph.D. and LL.D. were conferred upon him by Princeton and Trinity, respectively. On February 6, 1890, he was appointed a Chevalier of the Legion of Honor, upon recommendation of the Director and members of the faculty of the *École des Mines*, in recognition of his distinguished services to science and to that institution. In 1895 he received the exceptional rank of an Officer of the Legion of Honor, and had he lived but a month longer, the rank of Commander of the Legion of Honor would have been bestowed upon him, that distinguished body having decided to confer, and prepared the preliminaries for giving, such a decoration.

About five years ago, a public anniversary reception was held by the Department of Mineralogy of the Brooklyn Institute of Arts and Sciences, at which he was the formal guest of honor. A large and select audience was present to greet him; and an exhibition of minerals and mineralogical apparatus was a feature of the evening, to which was specially added a displayed collection of all Prof. Egleston's principal publications. On that occasion he was welcomed in addresses which recognized his great work for American science in organizing the School of Mines. He responded in an address of much vigor, in relation to science and public education, and the purposes and aims of the Brooklyn Institute as bearing on those aspects. He afterwards remarked to a friend that he had felt much gratified by this occasion; that he had had abundant recognition from his scientific associates, but that this was the first public testimonial that he had ever received.

Although possessed of immense nervous energy, which showed itself in his rapid speech and movement, Prof. Egleston

was a man of rather slight physique, and his constitution repeatedly gave way under his many and exacting labors. In 1873 his health failed, and he was compelled to go to Europe, leaving the work of the young and fast-growing school to his assistants and colleagues.

In 1894 his health failed again, and in 1896 a second severe illness prostrated him. Upon his return he endeavored to resume his lectures, but the effort was too great and he requested to be retired. He was made Professor Emeritus, June 30, 1897, and thereafter, when his health permitted, devoted himself to preparing biographies of two of his ancestors. Though nearly to the last he spoke of again taking up scientific work, he evidently had little hope; and in 1898 he began disposing of his library and collections, giving nearly one thousand books to different departments of Columbia, his machinery and tools to the Department of Metallurgy, and his mineral collection to the Department of Mineralogy, saying that he preferred to do this while he lived, rather than leave the task to his executors.

To the very end he had retained his interest in the collection. The year of his retirement, when only able to work over the cases for a short period at one time, he insisted upon selecting and inserting the new specimens; and only a few months before his death he gave to the collection minerals obtained by him in the summer of 1899.

This was his last visit to Europe. During the previous winter and spring he had been seriously ill, and his friends felt much anxiety at his evident failure. It was while he was away that the sketch of his life and work, by his friend, Prof. Martin, already alluded to, appeared in the *Popular Science Monthly*. This article was highly appreciative and sympathetic; and on his return he read it with much gratification. It came none too soon. He was unable to resume any work, and after a few weeks of increasing debility he passed peacefully away Jan. 15, 1900, at the comparatively early age of 67. We honor his memory; we mourn his loss; and we treasure his example.

In closing this account of the life and work of Prof. Egleston, it is gratifying to note that his memory is to be fittingly honored in the institution which he founded and to which he devoted his life. The action of the Trustees of Columbia University, attaching his name to the mineralogical museum,

has already been mentioned. Since then, another recognition has been accorded him by the students and graduates. It is to take the form of a bronze bust of heroic size, representing Prof. Egleston in his academic gown, which will be placed in the University Memorial Hall, as the gift of the students of the University, in commemoration of the "Founder of the School of Mines." The model, by the eminent American sculptor, William Couper, has been finished, and a view of it accompanies this notice.

APPENDIX.

List of Books and Papers Published by Thomas Egleston.*

Catalogue of Minerals, *Smithsonian Miscellaneous Collections*, Vol. 7, Art. 9, 1863.

Catalogue of Minerals, arranged by their bases, Washington, 1863; republished in 1866 for use of students of School of Mines.

Plan for a School of Mines in the City of New York, New York, 1863.

A Check List of the Silicates, New York, 1866.

Diagrams to Illustrate Lectures on Crystallography (3 editions); first edition, New York, 1866.

Agricultural Survey of the First Hundred Miles of the Union Pacific Railroad, New York, 1866.

Tables for the Determination of Minerals (5 editions); first edition, New York, 1867.

Metallurgical Tables on Copper, Lead, Silver, Gold, etc. (2 editions), New York, 1868.

Tables of Weights, Measures and Coins of the United States and France (3 editions), New York, 1868.

Metallurgical Tables on Fuels, Iron and Steel (7 editions), New York, 1869.

Blanks for Collecting Statistics on Iron and Steel Metallurgy, Pamphlet, New York, 1871.

Catalogue of the Arrangement of the Collections of the School of Mines, New York, 1871.

Comparison of the Notations of Faces of Crystals, New York, 1871.

Tables for the Collection of Iron Statistics, New York, 1871.

Comparison of the Dimensions of American Blast-Furnaces, New York, 1870; also *Berg. u. Hüttenm. Zeit.*, Vol. 31, p. 281 (1872).

Lectures on Mineralogy (3 editions), New York, 1871.

Scheme for Qualitative Determination of Substances by the Blow-pipe, *Amer. Chemist*, Vol. 2, p. 383 (1872); also, *Smithsonian Report* for 1872, pp. 219–222.

Labels for Mineral Collections, New York, 1872.

Researches on the Abrasive Power of Sand on Diamonds and other Minerals, *Trans. Amer. Inst.*, 1872.

Uses of Blast-Furnace Slags, *Trans.* A. I. M. E., i, 206–215 (1872).

Analysis of Furnace-Gases (Description of the Orsat Apparatus), *Trans.* A. I. M. E., ii, 226–240 (1874).

---

* From the paper by Prof. Moses in the *School of Mines Quarterly*, already cited.

Angles of Tools, *Horological Journal*, April, 1873.

Investigations on Iron and Steel Rails, made in Europe in 1873, *Trans*. A. I. M. E., iii, 44 (1874).

Analysis of Rocks, *Id.*, iii, 94 (1874).

Notes on the Treatment of Mercury in North California, *Id.*, iii, 273–307 (1875).

Improvement in the Condition of Workmen, *Id.*, iii, 221 (1875).

Refractory Materials, *Id.*, iv, 257–273 (1876).

Investigations on the La Bastie Glass, New York, 1875.

Boston and Colorado Smelting Works, London *Engineering*, Vol. 22, pp. 199, 246, 289, 317 (1876); also, *Trans.* A. I. M. E., iv, 276–298 (1876).

Hunt and Douglas Copper-Process, London *Engineering*, Vol. 22, pp. 419, 437 (1876).

Canfield's Mineral Dresser, *Trans.* A. I. M. E., iv, 273–276 (1876).

Technical Education, Special pamphlet of the A. I. M. E., p. 95 (1876).

Sampling Ores in Colorado, London *Engineering*, Vol. 22, p. 495 (1876).

Boracic Acid in Lake Superior Iron Ores, *Trans.* A. I. M. E., v, 131, 132 (1876).

The Commercial Analysis of Furnace-Gases, *Id.*, v, 487–494 (1877).

Brückner's Cylinders for Roasting Silver Ores, London *Engineering*, Vol. 22, p. 515 (1876).

Reese River Process for the Extraction of Silver in Colorado, *Id.*, Vol. 23, p. 474 (1877).

Parting of Gold and Silver in California, *Id.*, Vol. 23, p. 375 (1877).

Extraction of Gold by Plattner's Process in California, *Id.*, Vol. 24, p. 119 (1877).

The Pelican Mill, Colorado, *Id.*, Vol. 24, p. 297 (1877).

Hydraulic Mining in California, *Id.*, Vol. 24, pp. 353, 409, 445, 485 (1877).

Copper-Dressing in Lake Superior, *Metallurgical Review*, Vol. 2, p. 227 (1878).

The Doyere Method of Analyzing Blast-Furnace Gas, *Id.*, Vol. 2, pp. 53–67 (1878).

Copper Mining on Lake Superior, *Trans.* A. I. M. E., vi, 275–312 (1877).

Thin Plates of Metal, *Id.*, vii, 91–93 (1878).

Structure of Rails as Affecting Railroad Accidents (read before N. Y. Acad. Sci.), abstract in *Science News*, Vol. 1, p. 68 (1879).

Researches on the Abrasion and Wear of Iron and Steel, Report of Progress, *Trans.* A. I. M. E., vii, 371 (1879).

Pan-Amalgamation of Silver Ores in Nevada and Colorado, London *Engineering*, Vol. 27, pp. 43, 128, 189, 369, 473, 491, 514 (1879).

The Chemical and Physical Properties of Steel Rails, *Trans.* A. I. M. E., vii, 371 (1879).

Treatment of Mercury in North California, London *Engineering*, Vol. 28, pp. 239, 277, 331, 407, 463 (1879).

California Stamp Mills, *Id.*, Vol. 30, pp. 19, 85, 163, 255, 338 (1880).

The Iron of our Railways, *Science News*, Vol. 1, p. 68 (1879).

The Law of Fatigue and Refreshment of Metals, *Trans.* A. I. M. E., viii, 398–404 (1879).

Parting Gold and Silver, *School of Mines Quarterly*, Vol. 1, p. 43 (1880).

The Manufacture of Charcoal in Kilns, *Trans.* A. I. M. E., viii, 373–397 (1879).

The American Bloomary Process for Making Iron Direct from the Ore, *Id.* viii, 515–550 (1879).

On Zinc Desilverization, *Annals of the N. Y. Acad. of Sci.*, Vol. 2, p. 80 (1882).

Treatment of Silver Tailings in Nevada, London *Engineering*, Vol. 30, pp. 395, 451 (1880).

Treatment of Gold Quartz in California, *Id.*, Vol. 31, pp. 246, 323, 403, 532, 605 (1881).

Copper Refining in the United States, *Trans.* A. I. M. E., ix, 678–730 (1880).

The Formation of Gold Nuggets and Placer Deposits, *Id.*, ix, 633–646 (1881).

The Cause of Rustiness and of some of the Losses in Working Gold, *Id.*, ix, 646–650 (1881).

Parting Gold and Silver in California, *Report of the Director of the U. S. Mint for* 1880, pp. 356–363 (1881).

Investigations on the Ore Knob Copper Process, *Trans.* A. I. M. E., x, 25–57 (1881).

The Progress of the Metallurgy of Gold and Silver in the United States, *School of Mines Quarterly*, Vol. 3, pp. 71–102, 157–171 (1882).

Presence of Tellurium in Copper, *Trans.* A. I. M. E., x, 493–495 (1881).

Treatment of Enargite, *School of Mines Quarterly*, Vol. 4, pp. 5–9 (1882).

The Appointment of a United States Government Commission of Tests of Metals and Constructive Materials, *Trans. Amer. Soc. Mech. Eng.*, Vol. 3, p. 80 (1882).

The Method of Collecting Flue-Dust at Ems on the Lahn, *Trans.* A. I. M. E., xi., 379–411 (1883).

Leaching Gold and Silver Ores in the West, *Id.*, xii, 40–63 (1883).

An Accident to Steam-Pipes Arising from the Use of Blast-Furnace Wool, *Trans. Amer. Soc. of Civil Eng.*, Vol. 12, pp. 253–266 (1883).

The Patio and Cazo Processes for Amalgamating Silver Ores, *Annals of N. Y. Acad. of Sci.*, Vol. 3, pp. 1–66 (1883).

Some Researches on the Amalgamation of Gold and Silver, *Trans.* A. I. M. E., xii, 379–386 (1883).

A Machine for Testing the Physical Properties of Metals and Alloys, *Trans. Am. Soc. Mech. Eng.*, Vol. 5, pp. 140–156 (1883).

Biographical Notice of Louis Gruner, *Trans.* A. I. M. E., xii, 126–130 (1883).

Russell's Leaching Process, London *Engineering*, Vol. 38, p. 239.

Gases Contained in Steel, *School of Mines Quarterly*, Vol. 5, pp. 224–235 (1884).

Haswell & Whitworth's Steel Forgings, *Id.*, Vol. 6, pp. 216–224 (1885).

Parting Gold and Silver by Means of Iron at Lautenthal, *Report of Director of U. S. Mint for* 1880, pp. 363–366; also, *School of Mines Quarterly*, Vol. 6. pp. 240–251 (1885).

Bessemerising Copper Mattes, *Id.*, Vol. 6, pp. 320–335 (1885).

Going into Blast with Anthracite Furnaces, *School of Mines Quarterly*, Vol. 6, pp. 358–370 (1885).

The Separation of Silver and Gold from Black Copper at Oker, *Report of Director of Mint on Prod. Gold and Silver in U. S.* in 1884, pp. 599–604 (1885).

Treatment of Roasted Pyrites by the Longmaid & Claudet Processes for the Extraction of Gold and Silver, *Trans.* A. I. M. E., xiv, 98–118 (1885).

Parting Gold and Silver in the U. S. Assay Office, New York city, *School of Mines Quarterly*, Vol. 7, pp. 1–23 (1885).

Basic Refractory Materials, *Trans.* A. I. M. E., xiv, 455–492 (1885).

Basic Open-Hearth Steel Process, *School of Mines Quarterly*, Vol. 7, pp. 49–66 (1885).

Basic Bessemer Process, *Trans. Am. Soc. Mech. Eng.*, Vol. 7, pp. 34–80 (1885).

On Some of the Physical Properties of Iron and Steel, *Id.*, Vol. 7, p. 249 (1885).

The Stetefeldt Furnace, London *Engineering*, Vol. 40, p. 293 (1885).

Rolls for Crushing Ore, London *Engineering*, Vol. 40, pp. 463, 487 (1885); reprinted, New York, 1886.

Cause and Prevention of the Decay of Building Stone, *Trans. Am. Soc. Civil Eng.*, Vol. 15, pp. 647–716 (1886).

The Disintegration of the Egyptian Obelisk in the Central Park, New York, *Trans. Am. Soc. Civil Eng.*, Vol. 15, pp. 79–84 (1886).

Working Placer-Deposits in the United States, *School of Mines Quarterly*, Vol. 7, pp. 101–131 (1886).

The Parting Process used in the United States Mint, at Philadelphia, *School of Mines Quarterly*, Vol. 7, pp. 253–283 (1886).

The Point Shirley Copper Works, *School of Mines Quarterly*, Vol. 7, pp. 360–384 (1886).

The Mendheim Continuous Gas-Furnace for Burning Fire-brick and Porcelain, *School of Mines Quarterly*, Vol. 8, pp. 34–54 (1886).

The Dunnachie Continuous Regenerative Gas Kiln for Burning Fire-Brick, Pottery, etc., *Trans.* A. I. M. E., xv, 488–504 (1886).

Treatment of Gold in the Arrastra, *School of Mines Quarterly*, Vol. 8, pp. 126–135 (1887).

Drift-Mining, *Id.*, Vol. 8, pp. 204–220, and 289–304 (1887).

The Metallurgy of Silver, Gold and Mercury in the United States, in two volumes: Vol. 1, Silver, 1887, 558 pp.

The Extraction of Copper at Agordo, *School of Mines Quarterly*, Vol. 9, pp. 124–139, and 256–278 (1888).

A Glossary of Furnace-Terms in English, French and German, *Trans.* A. I. M. E., xvi, 313–333 (1888).

Some Thoughts and Suggestions on Technical Education, *Id.*, xvi, 623–661 (1888).

The Treatment of Fine Gold in the Sands of Snake River, Idaho, *Id.*, xviii, 597–609 (1889).

Catalogue of Minerals and Synonyms Alphabetically Arranged for the Use of Museums, *Bulletin No.* 33, *of U. S. National Museum*, 1889.

The Thies Process of Barrel-Chlorination, *School of Mines Quarterly*, Vol. 11, pp. 138–147 (1890).

The Worth of Manual Training, *Educational Leaflet, No.* 57, *of College for the Training of Teachers*, 1890.

Cooking Schools, *Educational Leaflet, No.* 61, *of College for the Training of Teachers*, 1890.

The Metallurgy of Silver, Gold and Mercury in the United States, in 2 Volumes: Vol. 2, Gold and Mercury, 1890, 920 pp.

Obituary Notice of James Buckton Mackintosh, *School of Mines Quarterly*, Vol. 12, pp. 256–259 (1891).

The Treatment of Copper Slates at Mansfeldt, *Id.*, Vol. 12, pp. 85–117, and 193–218 (1891).

Manufacture of Slag-Bricks in Montana, *School of Mines Quarterly*, Vol. 12, pp. 189–193 (1891).

Ancient Methods of Dividing and Recording Time in Japan, *School of Mines Quarterly*, Vol. 13, pp. 299–312 (1892).

Biographical Notice of Major Egleston of the Revolutionary Army, N. Y. *Genealogical and Biographical Record*, July, 1889.

The Life of Major-General John Paterson, G. P. Putnam's Sons, New York, 1895.

Remarks on Mine-Surveying Instruments, with Special Reference to Mr. Dunbar D. Scott's Paper on their Evolution,* and its Discussion.†

BY H. D. HOSKOLD, INSPECTOR GENERAL OF MINES OF THE ARGENTINE REPUBLIC, BUENOS AIRES, S. A.

(Canadian Meeting, August, 1900.)

SYNOPSIS.

I. Instrument-Parts and Implements.

Cross-hairs; Stadia-measurement; Fineness of Graduation; Cylindrical Graduation; Nonius; Vernier; One Vernier or two; Leveling-Screws; Troughton & Simms' Shifting Tripod-Head; Hoskold's Shifting Tripod-Head; Hoskold's Extensible Tripod; Electric Lamp; Plumb-lines; Chain.

II. Instruments.

Compass (Mine-compass of 1518, Compass of 1541, and Agricola's of 1556, Voigtel's Setz-compass, Circumferentor, Stanley's Hedley Dial, Compass on Telescope, Hanging Compass, Lack of Precision); Plane-table; Octant and Quadrant; Theodolite and Transit (Evolution of the Theodolite, Scott's Tachymeter, Hoskold's Engineer's Theodolite, Angleometer, Precision of Mine-Theodolites).

I. Instrument-Parts and Implements.

Cross-Hairs.—Mr. Scott‡ says Lean's dial

"might also have been provided with a diaphragm and cross-hairs; for Huygens discovered that any object placed in the common focus of the two lenses of a Kepler telescope (1611) appeared as distinct and well defined as any distant body. Following this established theory, in 1669 Jean Picard, Marquis Malvasia and others crossed silken fibers in the mutual focus of their astronomical instruments."

If by this Mr. Scott means that Huygens and Picard first devised and applied cross-hairs to the focus of the telescope, the writer cannot agree with him. Huygens did not describe "his telescope without tubes until 1684, in his *Astroscopia Compendiaria.*"§ Moreover, it is recorded that the English astronomer, Gascoigne,||

---

* *Trans.*, xxviii., 679. † *Trans.*, xxix., 931. ‡ *Trans.*, xxviii., 697.
§ *Universal Biography*, Mackenzie, p. 968. || *Ibid.*, p. 564.

"was the first who placed crossed filaments at the common focus to mark the center, axis or line of collimation of the telescope, enabling that line to be directed towards the object to be observed."

In another place it is stated that this invention took place in 1640.* Picard, originally a priest, did not become an assistant astronomer to Gassendi earlier than 1645.

Stadia-Measurement.—If Mr. Brough and Mr. J. L. Van Ornum† intend to convey the idea that James Watt, in 1770–1771, was the first to discover special means for the determination of distances upon the surface, without direct measurement by a chain or other linear measurer, then they have fallen into a grave error; for, it is recorded that Gascoigne "invented the micrometer, which by measuring the apparent size of the image ascertained the angle subtended by the object."‡

Gascoigne's two inventions—placing cross-hairs in the focus of the telescope, and the micrometer—by which the telescope was first adapted to observing exactly the position and apparent size of the heavenly bodies and of "distant objects on the earth, are the most important improvements which have been made in astronomical and geodetical instruments since the invention of the telescope. Their date lies somewhere between 1638 and 1643."§ Again, it is declared|| that the micrometer of Gascoigne "may be considered the prototype of our best spider's line micrometer." Gascoigne also measured the diameter of the sun and moon and the angular distances of the stars in the Pleiades by his micrometer in 1640.¶ Oughtred also received a letter from Gascoigne in 1640–41, referring to his newly invented micrometer.** Townley†† says of Gascoigne:

"Before our late Civil Wars, he had not only devised an Instrument of as great a power as M. Auzout's, but had also for some Years made use of it, not only for

* Hoskold upon *Ancient and Modern Surveying and Surveying Instruments, Trans. Am. Soc. Civ. E.*, vol. xxx., pt. ii., pp. 135–154 (1893).

† *Trans.*, xxix., 934, 1898.

‡ *Universal Biography*, Mackenzie, p. 564, and Pearson's *Astronomy*, pp. 92–93, 1829.

§ *Universal Biography*, Mackenzie, p. 564, and *Phil. Trans.*, 1737.

|| Pearson's *Astronomy*, p. 93, vol. iii., 1829.

¶ Flamsteed's *Prolegomena*, *Historia Cœlestis*, vol. iii., p. 95.

** *Phil. Trans.*, vol. xlviii., p. 191, 1753.

†† *Phil. Trans.*, No. 25, p. 457, May, 1667, and Pearson's *Astronomy*, p. 92, vol. iii., 1829.

taking the Diameter of the Planets, and Distances upon Land; but had farther endeavour'd, out of its preciseness, to gather many Certainties in the Heavens; amongst which I shall only mention one, *viz.*, The finding of the *Moons Distance.*"

The micrometer or distant-measurer of Gascoigne was capable of marking 40,000 divisions in a foot with the help of two indexes. The result was that he could measure an object to a single second of arc.* The micrometer employed by Auzout and Picard only measured from 20 to 30,000 parts of a foot.† The words just quoted, "distances upon land," are exceedingly important for the purpose of determining the question under discussion; for, although James Watt may have made such an invention in 1771 as that attributed to him, still the authorities quoted place it beyond doubt that Gascoigne was the first Englishman to invent and apply a distant-measurer.

Fineness of Graduation.—Mr. Scott declines to continue the discussion of the relative merits of the *minute-graduations* as compared with finer divisions; but the writer is of opinion that after the demonstration given by him‡ the minute-division theory is untenable. As Mr. Scott has pointed out,§ if we assume an isolated case, and say that there would be an error of 30″ on a line of 100 feet, the deviation would be too insignificant to be noticed; and, although the proposition is ingeniously put, still it is not stating the whole case. Taking it for granted, as Mr. Scott says, that a minute-vernier can be read without greater error than 30″, the error would be a continuous one, frequently repeated, and increasing according to the number of lines in the survey minus one; and if the distances were equal and the error angle had the same sign, we should be tracing a slow curve, and the total deviation-error in arc would equal the number of lines minus one multiplied by 30″. The same principle is involved in an underground survey, with the difference that the length of the lines would vary. To be sure, the error-angle would sometimes be a positive and at others a negative quantity, and for this reason some engineers, surveyors and mathematicians have stated that the one would balance the other. But they forget that such an effect could

* Pearson's *Astronomy*, p. 92, vol. iii., 1829.

† *Phil. Trans.*, No. 21, p. 373, Jan., 1666.

‡ *Trans.*, xxix., 978, February, 1899.

§ *Trans.*, xxix., 985, February, 1899.

not result unless the lengths of the lines were equal, and the error-angle always had a positive and negative effect alternated, or in reciprocal succession, conditions which could not occur. There is no excuse or reason in advocating that, because some careless persons elect to use a rough line-measuring instrument, the divisions of a theodolite-vernier should be no finer thân a minute of arc.

Cylindrical Graduation.—Messrs. Wittstock's idea of putting the graduation on the edge of vertical circles, instead of upon the flat side, is not new.* Instruments were divided on the cylindrical edge some thirty years since by Troughton & Simms, of London. The writer once inspected in their noted establishment various instruments of this kind which had been constructed for use in the great Indian Survey. The mathematical instrument-maker Cooke, of York, adopted the same plan many years since for his new form of transit-theodolite, Fig. 136.

Nonius.—The reading of fractional parts of a degree on astronomical and surveying instruments was much facilitated by the invention of Nonius or Nuñez,† about 1542; but his plan gave place to the more accurate mode of Digges.‡ Tycho Brahé is said to have adopted this invention—*i.e.*, the subdivision of a degree into fractional parts by means of diagonal lines—and applied it to his quadrant, dividing it into minutes, somewhere between 1566 and 1570.§ This system was employed in Germany for a considerable time afterwards.

Vernier.—The plan of subdividing by diagonal lines was finally superseded about 1631–2 by the more accurate, convenient and facile system of subdividing introduced by Vernier, a method that has not been superseded nor ever will be; except for excessively fine readings, which can only be conveniently obtained by the use of the *micrometrical microscopes* applied to the larger instruments.

---

* *Trans.*, xxix., 1001, 1899.

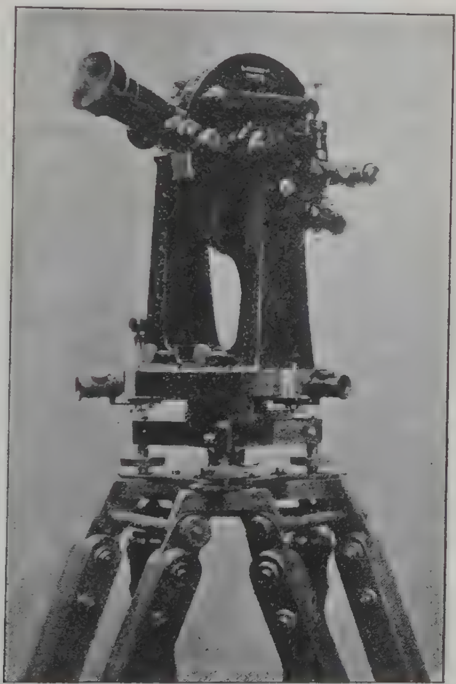
† The system is explained in the book of Nonius entitled *De Crepusculis.*

‡ *Alæ Seu Scalæ Mathematicæ*, Thomas Digges, London, 1573. [See also *Trans.*, xxix., 986 and 987, for an illustration and the history of this method of subdividing angles, the so-called diagonal scale, or method of transversals.]

§ *Universal Biography*, Mackenzie, p. 854. [Brahé's great quadrant of 14 cubits, about 19 feet, in radius, was built at Augsburg in 1569. See Dreyer's *Tycho Brahé*, 1891, p. 32.]

One Vernier or Two.—The one double vernier described by Messrs. Wittstock* is much less satisfactory than two single verniers placed on opposite sides of a circle; simply because the latter plan affords the means of taking an average of readings from two parts of the circle at the same time, so as to reduce the effect of eccentricity and errors of graduation. But with one vernier, although double, as proposed by Messrs.

FIG. 136.



Cooke's Theodolite.

Wittstock, such errors, if they exist, must remain without correction. Possibly, however, this objection may be met by the statement that such refinement is not required for mine-surveys. The best English mathematical instrument-makers, writers and other scientific men have long since recognized the principle just noted, and have provided means for the reduction of such errors to a minimum. Generally, therefore, three equidistant verniers are provided for the horizontal circle of theo-

* *Trans.*, xxix., 1003, 1899.

dolites from 6 to 8 inches in diameter. As far back as 1858 three verniers were attached to the vertical circle of the miner's transit-theodolite, Fig. 74;* and the same plan has been continued and applied to the horizontal circle of Fig. 75,† also with the addition of double readings to the vertical semicircles.

Leveling-Screws.—With reference to the mode of leveling-up surveying and spirit-level instruments, Mr. Stanley admits that there is a "strain put upon the axis of the instrument by the use of four leveling-screws," but he considers it "unimportant." It is nevertheless certain that anything defective in the construction of an instrument tends to disturb or destroy its absolute stability; and, for that reason, any defect, however small, should be removed. The strain referred to is augmented when the instrument is top-heavy. The four conjugate screws formerly attached to theodolites and spirit-levels, and admired so much by the old school in England, until a new practice was introduced, were placed between the parallel leveling-plates, with so short a leverage from the vertical axis of the instrument to the center of the screws that they never admitted of a facile and permanent mode of leveling. Especially has this been felt when surveys were made upon severely-inclined land; so that the difficulties have led inexpert persons to introduce the Hoffman patent joint attachment, as an additional means to assist in leveling with four screws. However, in the hands of expert surveyors, this appendage is unnecessary.

The tendency of each pair of leveling-screws placed between the parallel leveling-plates is to produce opposing forces, with the result that there is an expansion of the weakest part of the metal forming the small diameter of the screws; and consequently a corresponding displacement of the spirit-bubbles and of other parts of the instrument ensues. Besides, a locking of the screws sometimes takes place; and the retouching of the screws for any small displacement, as well as the original leveling-up, requires the use of both hands.

The present practice in England, and through a large part of South America, Australia, etc., requires a long equilateral triangular framed base, with three large leveling-screws attached to the theodolite; and this arrangement is very effective,

* *Trans.*, xxix., 962.

† *Trans.*, xxix., 964.

and a complete remedy for all such defects and inconveniences as are experienced from the old-fashioned form of four leveling-screws and parallel leveling-plates. With three leveling-screws there is no opposite pulling effect, because each screw is independent in its action of the others; and for correcting any displacement of the spirit-bubbles the use of one hand only is required.

Troughton & Simms' Shifting Tripod-Head.—Figs. 137, 138 and 139 exhibit separate parts of the triangular centering-apparatus—three horizontal plates, all turned upside down, as if the tripod had been completely overturned, with its feet pointing to the sky, and with the plates fallen apart downwards in regular order. Fig. 140, copied from Troughton & Simms' Catalogue of 1900, shows the whole apparatus right side up, as in

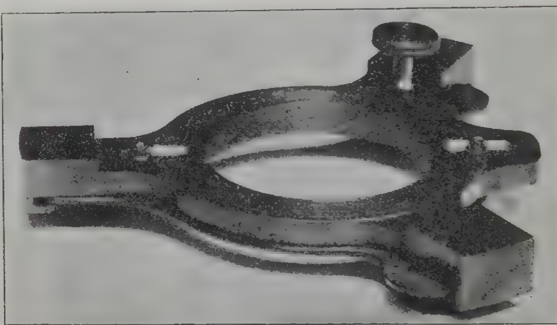
FIG. 137.

Shifting Tripod-Head, Bottom-Plate, Inverted.

use. The plate of Fig. 137 has a narrow slit about an inch long through it near each end; and a short, shouldered metal pin moves freely in each slit, and likewise fits into and moves freely in a corresponding slit near each end of the plate of Fig. 138, that, in use, rests upon the plate of Fig. 137. The slits of Fig. 138 are cut at right angles to those of Fig. 137; consequently the plate of Fig. 138 moves freely in two directions, at right angles one to the other, while both plates are held together by the shouldered metal pins. The large hole in the center of the plate of Fig. 137 has a female screw inside of it, and screws fast upon a corresponding male screw on the top of the tripod-stand head. To the upper side of the plate a hollow thin cylinder is cast, projecting upwards, with a male screw cut upon it. This projecting male screw passes through the large

central hole in the plate of Fig. 138 above; and is worked upon by the female screw inside the central hole of the circular clamp-plate, Fig. 139, which clamps the other two plates together. The plate of Fig. 139 has three small circular projections upwards (as shown in the figure, downwards), equidistant

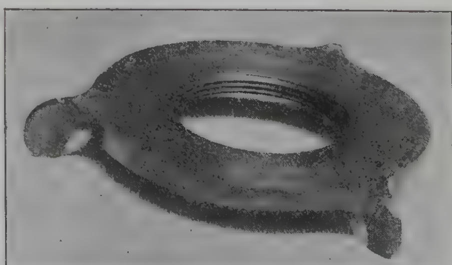
FIG. 138.



Shifting Tripod-Head, Shifting-Plate, Inverted.

one from the other (seen also in Fig. 140), forming an equilateral triangle, to which the thumb and fingers are applied when it is necessary to clamp and unclamp the plate. When the apparatus is put together for use, right side up, as in Fig. 140, the three conical-shouldered leveling-screws of the theodolite are

FIG. 139.



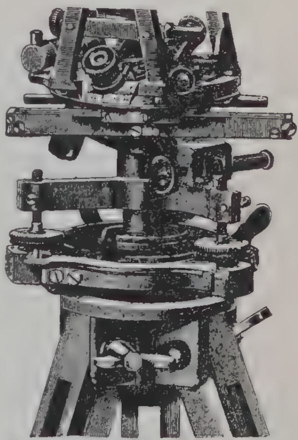
Shifting Tripod-Head, Clamping-Plate, Inverted.

placed in angular cavities in the upper surface of the triangular projecting ends of Fig. 138, and are then locked in that position by another thin plate, which has a slight horizontal motion, and is thereby secured in a groove by a conical head turned in the shank of the leveling-screws. Part of this thin plate is

seen projecting from under the (inverted) plate of Fig. 138, and it is clamped in position by the milled-headed screw also seen in Fig. 138. The construction and use of this simple, light and effective apparatus are well known. It is the invention of Troughton & Simms, and is supplied with all their instruments.

When the theodolite is locked in position upon this leveling and centering apparatus, and it is required to center it over a fine point marking a survey station, it is first done roughly by moving the legs of the tripod-stand, leveling up; and then the clamp-plate, Fig. 139, is unscrewed a little, leaving the theodolite and upper part of the leveling and centering apparatus, Fig. 138, free to move in two directions, at right angles one to another, upon the plate of Fig. 137, which is fixed upon the tripod-stand, until the fine point of the plumb-bob coincides with the center of the survey station. The circular clamp-plate, Fig. 139, is then screwed down tight, fixing the instrument in position for immediate use. The whole of these operations may be effected almost instantaneously.

Fig. 140.



Shifting Tripod-Head, Complete, Upright.

It is very important to possess some such means as those described to enable the engineer to center the theodolite over a survey station-mark with great precision and rapidity, because a greater geometrical approximation to the truth may be obtained. To do this perfectly by simply moving the tripod legs is difficult and almost impossible; and the attempt is the fertile source of a small repeated accumulating error, the total amount of which in an extensive survey cannot be estimated or determined until an irregular polygon has been described. The facilities for such control in underground surveys do not often exist.

Hoskold's Shifting Tripod-Head.—The top part of a theodolite-stand invented by the writer in 1866 consisted of a circular metallic box, to the underside of which the legs were attached;

and in the middle of the upper part a strong circular plate was fitted, having a circular motion of about one inch in all directions horizontally. At the center of the plate a large hollow screw was cast, projecting upwards to a height of about $1\frac{1}{2}$ inches, upon which the theodolite was screwed; but not close down, until, by moving the theodolite and plate about, the plumb-bob was centered over the station. The instrument was then screwed down ready for use.

Hoskold's Extensible Tripod.—That theodolite-stand of 1866 was planned for underground use, and each leg consisted of three tubes sliding one into another. On the outside termination of each tube a screw was cut, and the ends of the tubes were, at two places in each, slit up two inches in length by saw cuts, in order to compress the outer tubes against the inner ones when a stout outside collar screw was brought into action at each joint. In that manner the tubes were effectually clamped together. The stand could be set up from 18 inches to about 4 feet in height. But after some time the sliding of the tubes and the action of the collar-screw clamps were much impeded by water and dirt. Besides, the stand was too heavy. All of those inconveniences caused it to be abandoned. It may, however, be possible to construct a stand of this type in aluminum metal alloyed, so as to be of service. Nevertheless, three short stands of a special construction would be preferable. Part of the construction of the tubular stand noted was similar to that of Mr. Stanley's, referred to by Mr. Scott.*

Electric Lamp.—The small portable electric lamp mentioned by Mr. Scott is exceedingly convenient and useful, setting aside the use of candle lights and oil lamps, and facilitating in a high degree the reading of theodolite verniers underground. A diagram or graphic representation of it when in use in mine-surveys should have been introduced in Mr. Scott's discussion. Probably he will favor us with it on some future occasion. Fig. 84† shows to what extent inventions have been applied in order to achieve a similar purpose; but it is a cumbrous mode, and cannot be compared to the efficient little lamp described by Mr. Scott.

Plumb-Lines.—Mr. Hulbert is right in saying:‡

* *Trans.*, xxviii., 724, 725.

† *Trans.*, xxix., 991.

‡ *Trans.*, xxix., 1013, February, 1899.

"I should place more reliance upon a downward sight through a properly constructed and accurately adjusted telescope than in the repose of a plumb-line. We trust the telescope for the measurement of all horizontal distances, and we never question its accuracy in taking inclined angles and observations; now, therefore, why not accord it the same confidence in taking a truly vertical sight? Except for moderately short distances, I always considered the plumb-line a positive nuisance, a consumer of time and a disagreeable tester of patience."

He could also have added: without any positive certainty, for either long or short distances. It is nevertheless to be feared that persons will always exist capable of trying every obsolete fad.

Chain.—A steel standard chain is an expeditious measuring-instrument for underground work, and excellent results may be obtained by its use; at the same time, it is well to carry a pocket-rule divided to tenths of inches, for measuring any odd part of a link which may coincide with a station. Any tunnel or other important drivage from two opposite points, or otherwise, depending upon the survey, may then be carried out with confidence. For still more accurate work, another class of linear measuring instrument could be devised similar to those employed to measure base-lines in trigonometrical surveys, though simpler; but it would only be used on rare occasions.

II.—Instruments.

Compass.

Mine Compass of 1518.—Figs. 141 and 142 are two forms of mine-surveying compasses taken from the old rare German mining book, *Eyn woldgeordent und nützlich büchlin wie man Bergwerck' suchen uñ finden sol.* Edition 1518. This work with three other editions, namely, 1527, 1534 and 1539, are preserved in the Royal Mining Academy at Freiberg in Saxony. The 1504 edition of that book, the rarest of all, does not exist there. The compasses for mine-surveying—if they were so used—represented by Figs. 141 and 142 differ somewhat in form and size in all the editions of the book referred to. For example, Fig. 141, which appears to be the oldest, is divided into twice 12 hours, and has a small circle inscribed round the central point, upon which probably a small magnetic needle was placed. Fig. 142 has two concentric circles, each divided into twice 12 hours, one end of the magnetic needle being forked.

Compass of 1541 *and Agricola's of* 1556.—Mr. Brough, in discussing Mr. Scott's paper, said:*

"The author is inaccurate in stating that the use of the compass in mine-surveys is first described by Agricola."

It is, however, curious that Mr. Brough has conveyed the same sense and employed nearly the same words in his little book on *Mine-Surveying* from 1888 to 1899. At page 26 he says:

FIG. 141.

Earlier Mine-Surveying Compass of 1518.

"The use of the magnetic needle for surveying mines is first described by Georgius Agricola, in the fifth book of his *De Re Metallica*, 1556.

"The compass there described is of a very primitive character. . . . . An old compass of this type is preserved in the collection of the School of Mines of Clausthal, in the Harz. It bears date 1541."

The comparatively limited space of only three circular concentric grooves filled with wax, upon which to indicate the direction of underground roads, is, in the writer's opinion, enough to prove that the Clausthal compass is an older form than Agricola's. The latter was provided with seven circular concentric grooves filled with wax, and was consequently capa-

* *Trans.*, xxix., 932.

ble of being employed in more extended surveys, such as a progressive system of mining operations required. No doubt the mine-surveying compass of 1541 and Agricola's of 1556 are improvements upon the older forms, Figs. 141 and 142, of 1504 and 1518; for in these it would appear that anything finer than an entire division of one hour had to be estimated by some other means. On the contrary, the actual direction of any un-

Fig. 142.

Later Mine-Surveying Compass of 1518.

derground road was indicated by a scratched line on the wax of the Setz-compass and Agricola's compass.

Voigtel's Setz-Compass.—Mr. Scott has referred* to a very curious form of mine-surveying instrument, the astrolabe, a simple plane circle supported in a horizontal position, illustrated in an excellent old German book;† but he has omitted to note the Setz-compass of the same work, although it is equally interesting.‡ It has the same form as the surveying-

---

* *Trans.*, xxix., 984. † Voigtel's *Geometria Subterranea*, p. 146, 1686.

‡ *Ibid.*, p. 72.

compass of Fig. 141, date 1518. It seems, therefore, probable that that class of instrument may have been used for a period of two centuries, or more. The words midnight, midday and other names corresponding to certain defined points, engraved outside and around the circle or compass, indicate that it may have been a copy or a modification of some other more ancient instrument, say an astrolabe employed for some other class of observations, such as a rough estimation of time and general direction. A very curious group of ancient mathematical instruments forms part of the artistically engraved frontispiece of the same book, and would be worth reproducing.

Circumferentor.—The circumferentor described by Bion is nearly the same as the miner's dial-circumferentor with plain sights as constructed to-day, but is a little ruder in form than Fig. 12* in Mr. Scott's paper. It appears that Pryce did not know anything about this old dial in 1778.

Stanley's Hedley Dial.—Mr. Stanley recently introduced, as he says, a new form of Hedley dial, patented, Fig. 63.† It is constructed with an oval-shaped curved cradle carrying the telescope, and having a vertical circle attached, instead of with a ring and semicircle, as in the old type dials, Figs. 25 and 40.‡ The principal advantage to be derived from a vertical circle is that it offers means for obtaining two readings, one opposite the other; but Mr. Stanley has not availed himself of this established principle, making the circle, therefore, no more important than a semicircle. In this age of unprecedented progress, facility and accuracy of working, no practical person should prefer the old-fashioned and coarse method of engraved corrections "in hypothenuse and base" upon an instrument, when the same thing in an accurate form is included in a table of natural sines and cosines.

Mr. Stanley says: "It is the first dial of the Hedley style, I believe, which may be used for sighting in true verticality." But he has provided no means to adjust the horizontal axis upon which the cradle and telescope work; at least, such an adjustment is not described, nor does it appear in Fig. 63. Consequently, there is no certainty that the vertical hair of the telescope would under all conditions revolve permanently in the

* *Trans.*, xxviii., 692.

† *Trans.*, xxix., 939.

‡ *Trans.*, xxviii., 709 and 723.

same vertical plane. Considering this and the comparatively rough construction always inherent in this class of instrument, the writer is of opinion that it would not be a convenient or absolutely trustworthy instrument for carrying out that very delicate and important operation of connecting underground workings one to another and to the surface, for the purpose of executing some important and costly work. If, however, the contrary held good, the telescope is not conveniently constructed for facile work: neither is it sufficiently powerful except for comparatively short distances down pits or severe inclines, or for surveys of no great importance. The instruments of both Figs. 40 and 63 and all others of that type are comparatively cumbrous, rough in construction, and neither the one nor the other can ever be made to approach the nice and beautiful construction of a well-proportioned and high-class theodolite. Doubtless, however, many persons will employ the one of Fig. 63 for second-rate underground surveys in which great accuracy is not considered a *sine qua non*.

If Mr. Stanley desires to improve his instrument, and so render it of greater value for mine-surveying, it would be well to provide an adjustment to the horizontal axis, supply an axis level and means to illuminate the cross-hairs in the focus of the telescope. The best means of doing this is exhibited in Figs. 76 and 77.* An oblong hole is cut in the side of the telescope near its eye end and filled with glass, with a slide for protection. A reflector may be placed inside to throw the light upon the wires. If a magnetic bearing is of any value, the instrument of Fig. 63 would preferably have a more open dial face; for, in its present form, it would be difficult to obtain a clear view all round the circle, even when the cradle and telescope are tilted to the perpendicular. If the magnetic compass should be required at all, it would be best mounted on the top of the telescope, as is the case in the writer's Engineer's Theodolite, Fig. 76.†

Compass on Telescope.—The sliding magnetic compass was attached to the telescope of the theodolite, Fig. 17,‡ many years since by the writer; and the same plan has been continued for his Engineer's Theodolite, Fig. 75.§

* *Trans.*, xxix., 969 and 970.

† *Trans.*, xxix., 969, Feb., 1899.

‡ *Trans.*, xxviii., 698.

§ *Trans.*, xxix., 964.

Hanging Compass.—Referring to the remarks of Mr. Johnson* upon Mr. Scott's opinion as to the magnetic hanging compass in mine-surveying, the writer agrees with Mr. Johnson in a limited sense. That is, when the purpose of the survey is merely to obtain a rough diagram of the workings in a mine, the general direction of any mineral vein, and a variety of other things, without aiming at an exact map or plan of such underground objects with relation to the surface, to boundary lines, to the formation of a tunnel from two opposite points, or to striking any given bore hole, and to other important matters; then, any handy inexpensive magnetic compass may be employed, and time, inconvenience and money saved. It is evident, therefore, that a finely divided theodolite should not be taken into every hole and corner of a mine. However, when all the conditions just indicated are reversed, then such instruments as would enable the surveyor to produce the most accurate results should be employed, and the amount of time and expense necessary to effect this should not be considered.

Lack of Precision.—It is strange that some men continue to urge that the use of the magnetic compass is sufficient for underground surveys, and it is difficult to assign a reason; though we may assume that facility and simplicity of use, hereditary custom and the comparatively small cost of such instruments are some of the chief reasons why the miner's compass is still clung to in some form or another so tenaciously. But in the face of a well-known law of Newton are we to ignore the results of the modern solution of some of the most curious, difficult and important natural physical problems?

The scientific men of to-day have proved that even the highest class surveys, which have been conducted upon the most refined and rigid mathematical principles, are affected in a variable degree through the deflection of the plumb-line by close neighboring mountain masses and rocks of the greatest density. One of the most interesting and important records we possess is that which relates to the setting out of the boundary-line between the territory of the United States and the possessions of Great Britain between the Lake of the Woods and the Rocky Mountains. The part of the report of the chief

* *Trans.*, xxix., 993.

astronomer and member of the mixed commission that relates to the deviation of the boundary-line, as set out, from the true astronomical parallel of latitude, is applicable to the question to which the writer desires to direct attention. He says:*

"The fact of local deflection being established, the attention of mathematicians was turned to the investigation of the causes and probable corrections. In this much ingenuity has been displayed, but with very small results. Starting with the general law [of Newton], that every particle of matter attracts each other particle with a force varying directly with the mass and inversely with the square of the distance, the attraction of masses of mathematical forms on distant particles was found by dividing mountain-ranges and other elevations into volumes bearing known mathematical relations. The probable deflection of the plumb-line due to such causes was found for different distances, on the supposition that the mean density of the large volumes was uniform for different parts of the earth's crust [—a thing quite impossible]. Thus, it was found that at the northern station of the great Indian arc the attraction of the Himalayas should cause a deflection of 28″; which should decrease at the next two principal stations by 15″.9 and 21″.1, respectively, while the deficiency of matter in the ocean should produce similar northern deflections. These calculations were not absolute, since the contour of the mountains and of the ocean-bed was only approximately known; but the approximations were supposed to be sufficiently close. It was found, however, that the actual deflections were much smaller than those given by calculation; and that, in many cases, the deflection was towards the ocean. The explanation of this lies in the varying density of the earth's crust. The facts discovered indicate that the density is greatest in the depressed, and less in the elevated portions."

From the doctrine here laid down, upon Newton's law, we must conclude that the maximum density and effect occurs from the presence of intrusive dikes which have penetrated the earth's crust to a great extent; and, although some of those dikes are not visible, still the denser masses of such intrusions produce very great effect. As every one knows, the magnetic needle consists of a light bar of steel suspended freely upon a fine central point, and in a horizontal position. Consequently it is liable to be acted upon and deflected an unknown quantity by the greater and denser masses of rocks which form intrusive dikes. This effect may exist, although not suspected; but whatever its amount may be, it is independent of the deflection of the needle caused by ferruginous masses and the

---

* *Reports upon the Survey of the Boundary between the Territory of the United States and the Possessions of Great Britain*, Department of State, Washington, 1878, p. 263. Also in *Executive Documents, Senate of United States*, 1877, No. 41, p. 26, Washington, 1877.

other common deviations to which the magnetic needle is subjected.

The writer is nevertheless aware that magnetic surveys are sometimes conducted in places more or less free from natural disturbances; and, in such a case, when great care has been taken in manipulating the instrument, and when there has been a large share of good luck, close approximation to the truth has resulted. But such favorable conditions cannot always be expected to be realized. It would therefore be dangerous to place too much reliance upon the accurate performance of the magnetic needle on all occasions and under varying circumstances. The history of mine-surveying proves that some persons have placed absolute reliance upon the magnetic needle, and have come to grief. The erratic behavior of the magnetic needle, and consequently the uncertainty of the observations made with it, as just indicated, are confirmed by Mr. Hulbert*; and in addition to the list of disturbing elements previously noted, he has noted another, namely, "electric currents following either wall of a vein" of mineral.

Plane-Table.

Referring to Mr. Scott's discussion, a plane-table similar to that described under Fig. 62† was in use in England and France more than 120 years earlier. An old English work translated from the French‡ says, in substance, somewhat condensed:

"The plain-table is a parallelogram of wood, 15 inches long and 12 broad," having "a box-frame to fasten a sheet of paper upon the table, by forcing down the frame and squeezing in the edges of the paper, so that it lies firm and even upon the table; and thereby the plot of a field, or other enclosure, may conveniently be drawn upon it. On both sides of this frame, near the inward edge, are scales of inches subdivided into 10 equal parts, having their proper figures set to them. The use of these scales is for ready drawing of parallel lines upon the paper, and also for shifting the paper when the sheet will not hold the whole work. Upon one side of the box-frame are projected 360 degrees of a circle, from a brass center hole in the middle of the table. Each degree is subdivided into 30 minutes, and to every 10th degree are set two numbers, one expressing the proper number of degrees, and the other the complement of that number of degrees to 360. This is done to avoid the trouble of subtraction in taking angles. On the other side

* *Trans.*, xxix., 1011, February, 1899. † *Trans.*, xxix., 938.

‡ Stone's Bion, *Construction of Mathematical Instruments*, p. 127 and Fig. F, plate xiii., London, 1723.

of the frame and upon a part of its width are projected the 180 degrees of a semicircle from a brass centre hole in the middle of the table's length. Each degree is subdivided to 30 minutes; to every 10th degree are set likewise, as on the other side, two numbers; one expressing the proper number of degrees, and the other the complement of that number of degrees to 180. . . . . All these degrees will make the plain-table a theodolite or a semicircle, according to what side of the frame is uppermost. There is a box with a needle and card, covered with a glass, fixed to one of the long sides of the table. There is also belonging to the table an index, which is a large brass ruler, at least 16 inches long and 2 inches broad, and so thick as to make it strong and firm, having a sloped edge, and two sights screwed perpendicularly on it. Upon this index it is usual to have many scales of equal parts; as also diagonals and lines of chords," etc.

From this and the description given by Mr. Scott,* there appears to have been no improvement in plane-tables from 1657† to 1834, when Simms wrote.

Octant and Quadrant.

In an old Latin book on surveying and astronomical instruments,‡ an instrument called an octant—the eighth part of a circle—is exhibited, together with various diagrams illustrative of its application. That work contains evidence that the instrument referred to was used prior to 1604, and at least up to 1612. Fig. 143 is a reduction of the original diagram of the octant, the length, or radius, of which was 15 inches. The limb has 5 concentric arcs engraved upon it, and it is a good example of subdividing the degrees into parts by diagonal lines. The distance from the first divided arc to the exterior one is 1½ inches, and the diagonal lines are drawn from the whole degree points on the first arc to the half degree points on the exterior arc. The diagonal lines are, moreover, divided by fine dots, so as to read to every two minutes. Fig. 144 shows two such instruments set up, with four observers determining a distance.

A quadrant without subdivisions by diagonal lines was used in England for surveying operations by Delamain in 1632.§ Circles were, however, employed before 1529 in Spain and

---

* *Trans.*, xxix., 938.

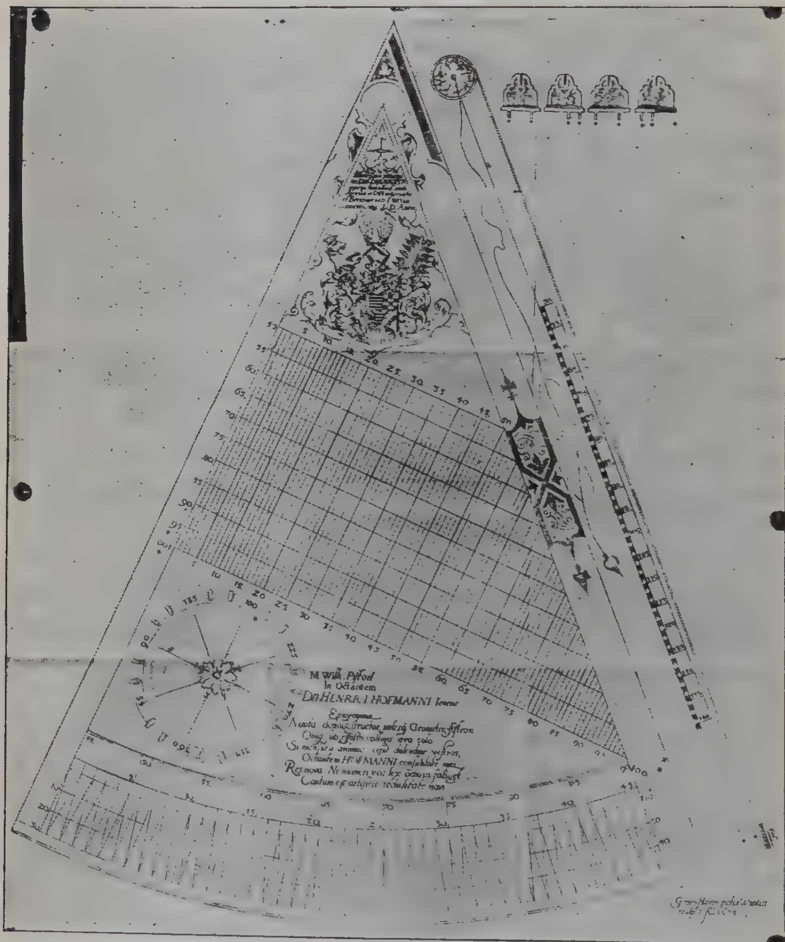
† *The Complete Surveyor, Containing the Whole Art of Surveying of Land by the Plane-Table, Theodolite, Circumferentor*, etc. Second edition, W. Lebourn, 1657.

‡ *De Octantis Instrumenti Mathematici Novi Geodætis, Astronomis, Nautis Usu*, etc. Henrico Hofmanne, Jena, 1612.

§ *A Mixed Trapezium or Horizontal Quadrant for Mathematical Practice*, Delamain, 1632.

other places. It is, therefore, somewhat strange that the use of octants and quadrants should have been continued in preference.

FIG. 143.



Octant.

Theodolite and Transit.

Evolution of the Theodolite.—The German instrument of Fig. 145 is illustrated in a curious black-letter book of 38 pages on surveying;* and, at the time, was considered to be of great

* *Instrument zur Mechanica*, A. Albrecht, 1673.

importance. It is possible that it was employed in mine-surveying. In the original description, A is a small compass-box, containing a magnetic needle, with the four cardinal points marked. B shows an indicator to which the compass-box is screwed, both of which revolve horizontally. C is a fixed graduated circle placed under the indicator B, and is divided

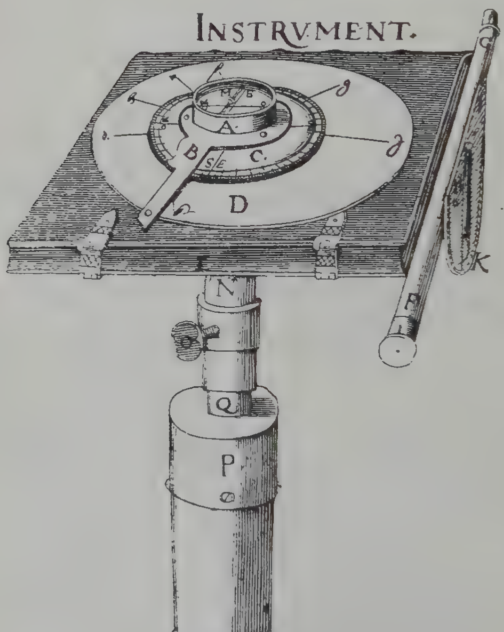
Fig. 144.

Octant in Use.

into 360°; also the four cardinal lines are marked upon it. D is a circular writing-table placed under the divided circle and extending concentrically beyond it. E is a bound book, part of the instrument, to which all the other parts, previously described, are firmly attached. The book was intended for writing and drawing. FG represents a tube or telescope, attached by means of a short axis and appendage to the side of the book.

A vertical semicircle was also fixed to the underside of the telescope, and the vertical angles were indicated by swinging pendulums suspended from the short horizontal axis previously noted. NQP represents the upper part of the stand, with joints for giving horizontal motion to the instrument. The cylindrical part at N appears to have been divided. When in use, the telescope of this instrument was directed to an object and the index bar, B, was then moved by hand round the divided circle,

Fig. 145.



Albrecht's Instrument.

until the magnetic needle pointed north and south; and the bearing angle of the observed object was then obtained from the divided circle.

The instrument* shown in Fig. 106† seems to be an improved form and probably derived from that of Fig. 145. In an old English book,‡ translated from the French, a graphometer, or surveying horizontal semicircle, is represented with

* *Geometria Forensis*, Reinhold, 1781, p. 106 and plate xii.

† Raymond's *Discussion of Scott*, *Trans.*, xxx., 799.

‡ Stone's translation of Bion, on *Mathematical Instruments*, p. 121, 1723.

double sights, the one fixed and the other movable, as in the instrument of Fig. 106, but without vertical motion for either of the sights. The upper telescope of Fig. 106, however, has a vertical motion, proving that it is of more recent construction, and approaching towards the simplest form of theodolite. The idea of attaching a vertical arc to the telescope of the instrument of 1781, Fig. 106, seems to have been derived from the large geodetic altazimuth of Ramsden, which at that time was so well known throughout Europe. Semicircles with plain sights were, however, mounted upon the diameter of horizontal circles about 1766.

The great inventor Ramsden completed his dividing-engine in 1773, after ten years of incessant labor, and his great 36-inch diameter theodolite, Fig. 146, soon after. Delambre styles him a "celebrated English optician, the greatest of all artists, and the inventor of the theodolite." To Ramsden is attributed the introduction of the vertical in combination with the horizontal circle in the same instrument. Ramsden constructed two 36-inch theodolites, one for the Royal Society, and the other for the English government. It is understood that both the instruments were employed on the English Trigonometrical Survey. One of them is still preserved in good working condition in the Ordnance Survey Offices. A notice of both instruments will be found in the *History of the Royal Sappers and Miners.**
The horizontal circle appears to have been read by four micrometrical microscopes and to one second of arc. The telescope was used for distances up to 112 miles.

Scott's Tachymeter.—The writer has made no objection to Mr. Scott's "interchangeable auxiliary telescope when placed on the top of the main telescope under conditions almost identical with the others mentioned."† All that can fairly be deduced from the writer's observations‡ is, that he considers the models Fig. 45 and Fig. 55 superior to all the other preceding ones described by Mr. Scott. It was not intended to include Figs. 56 and 57 in that list; but between these two a comparison was made in reference to the mode of attaching the auxiliary telescope, with its possible effects. However much experience a man may have,

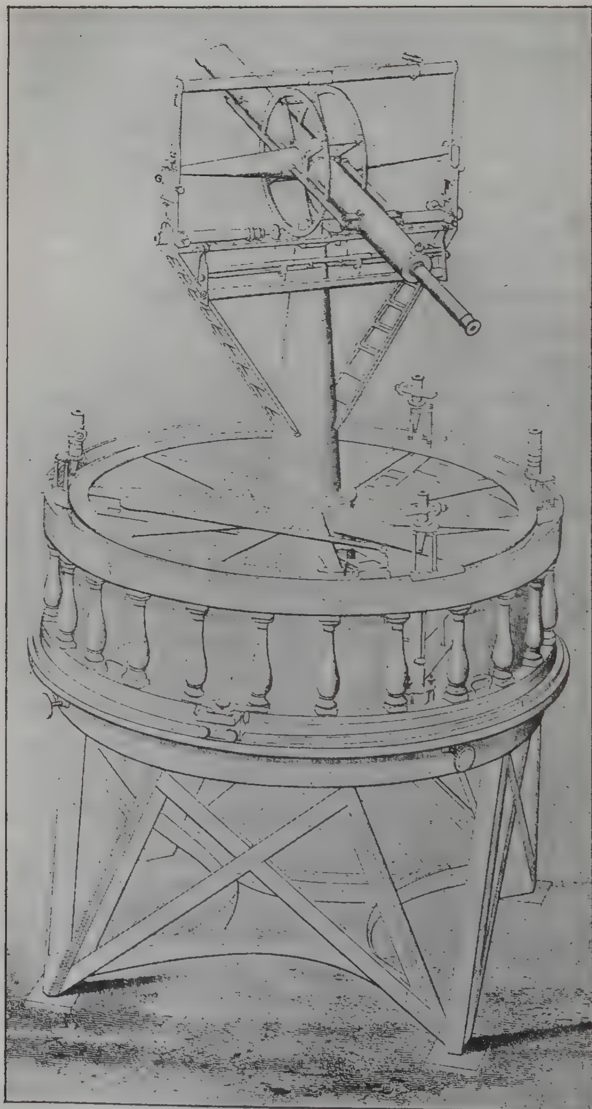
* *Royal Engineers*, 1857, vol. ii., p. 408.

† *Trans.*, xxix., 985.

‡ *Trans.*, xxix., 973.

it would be exceedingly unwise to attempt to criticise in too strict a manner the merits or demerits of an instrument he had not

Fig. 146.



Ramsden's 36-Inch Theodolite.

seen or proved. Considering, therefore, that Mr. Scott's form of instrument is a recent introduction, he naturally must be

the best expert with reference to its advantages and use, and we must consequently hear him, and give credit to his evidence. It is, however, difficult to convince men that the form of instrument they have been accustomed to use is not the best. This is the way and prejudice of the world, and it is a hard matter indeed to supplant entirely the old for the new, although the latter may be vastly superior.

Hoskold's Engineer's Theodolite.—Referring to Mr. Scott's remarks,* the writer cannot find sufficient reason to change the present form of his Engineer's Theodolite, Fig. 75,† to the form of an ordinary transit theodolite. The description which the writer has already given of that instrument‡ was intended to be sufficient to enable anyone to perceive the reason why it was constructed in its present distinctive form. When the design was last under revision, it was decided that, whilst the instrument should be adapted for general surveying use, it was also imperative that it should be kept as low down in construction as possible, and in as compact a form as convenience would permit. These conditions were necessary, considering that an instrument in that form would be better appreciated and useful among the more experienced surveyors in collieries and other mines and places where severe angles of depression do not so commonly occur, and where a higher and a more top-heavy instrument would be objected to, and would, in general, stand the chance of being excluded altogether.

The standards of the writer's Engineer's Theodolite, Fig. 75, are only 5⅛ inches in height, and the range of the semicircle is about 60° of depression to 70° of elevation, sufficient for most purposes, especially in surface-surveying operations. But, to meet a few exceptional underground cases, where the angle of depression amounts to 70°, the instrument may be planted at the bottom instead of at the top of the excavation, and the angle so measured would be equal to the one of depression. In the second place, the limit for the standards of this instrument is from 6⅜ to 7 inches in height; and, in this case, the instrument is capable of measuring an angle of depression of 66°, and one of elevation of 76°. However, if desired, the standards could be made 7½ inches high without detriment, and an angle of ele-

* *Trans.*, xxix., 984. † *Trans.*, xxix., 964. ‡ *Trans.*, xxix., 966.

vation could then be measured greater than 76°. Naturally, in extreme exceptional cases, such as those noted by Mr. Hulbert,* where the dip ranges from 83° to 86°, special means must be employed.

But when a mineral vein has a great dip "varying from 83° to 86°," as Mr. Hulbert says was the case in the Cliff mine, it is an error on his part to state that "no sight on this inclination could be taken with the ordinary transit-telescope." *The angle of depression of any given inclined plane observed from the top is equal to the angle of elevation of the same plane measured from the bottom.* If, therefore, an ordinary transit-telescope will not measure an angle of depression of 86°, or a larger angle, when the standards of the theodolite are only of a moderate height, it will measure that angle on the bottom of the excavation when the instrument is constructed in the form of Fig. 74.† That instrument is capable of measuring angles of elevation up to the zenith; and although the construction is comparatively simple, still it is very portable and handy, as also very effective. It was the favorite instrument of the writer in 1858, and a large number were, and still continue to be, constructed by various English makers for local and foreign use, especially in various parts of South America. It is, however, preferable when mounted upon a triangular leveling-base with three leveling-screws, as shown in the diagram in the right hand lower corner of Fig. 74.

The writer has clearly explained how his Engineer's Theodolite, Fig. 75,‡ can be applied in order to perform the work of a transit-theodolite; consequently there is no need to give it the form Mr. Scott suggests, or to introduce in it a cyclotomic circle; a plan, by the way, that Mr. Scott recommends, and does not adopt for his own instrument. The instrument of Fig. 75 is constructed with as much perfection as the present practice of mechanical and mathematical principles and skill will admit; and that fact, taken in connection with the exceptional advantages pointed out by the scientific Jury of Awards at the Chicago Exhibition, 1893,§ advantages experienced, too, in the practice of other engineers with the instrument, insures that it is unrivaled.

* *Trans.*, xxix., 1011, February, 1899.

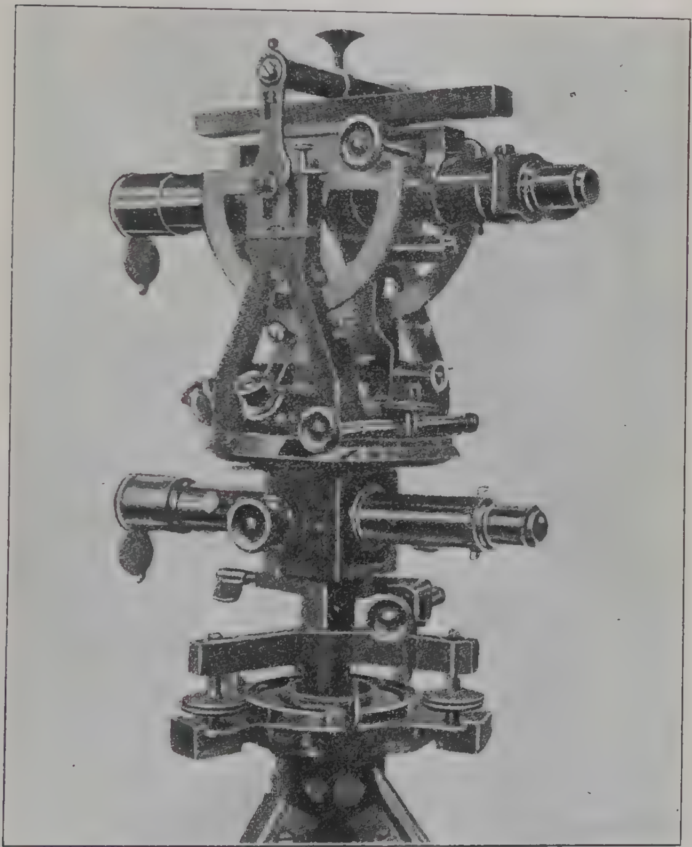
† *Trans.*, xxix., 962.

‡ *Trans.*, xxix., 964.

§ *Trans.*, xxix., 961, February, 1899.

However, if there are persons who cannot be convinced, or are not able to appreciate the construction and use of any other instrument than a transit-theodolite, Fig. 75 may be converted to that form by making the standards a little higher than they are at present, shortening the object-end of the telescope,

FIG. 147.



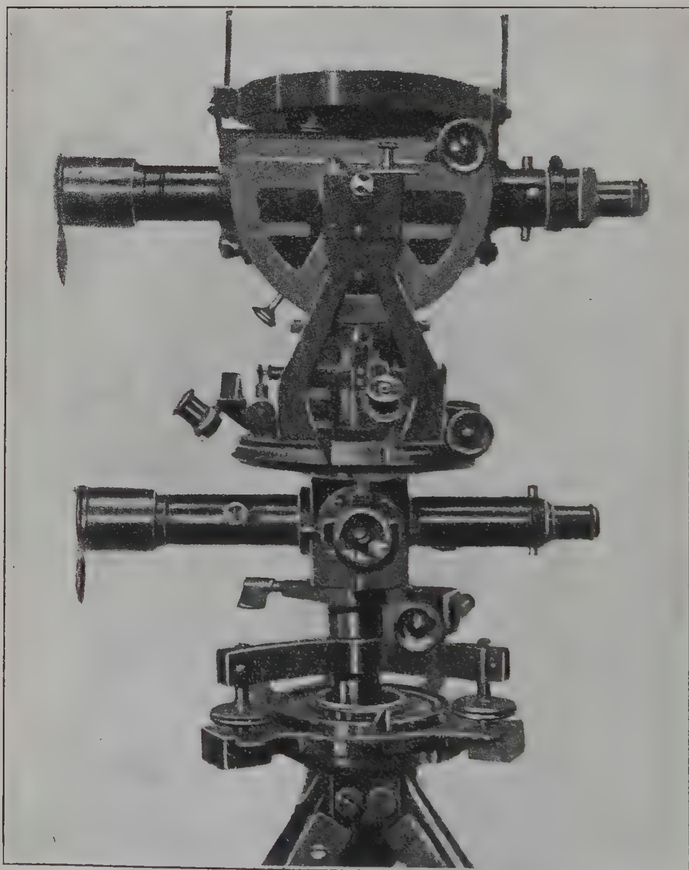
Hoskold's Engineer's Theodolite, Improved.

lengthening its eye-end, and making the object-glass and eye-glass interchangeable; so that the instrument may be used to sight objects in the zenith. In this way, and others to be pointed out, may be obtained a very effective and excellent transit-form of instrument, with the advantage that all the other parts may remain as at present. Nevertheless, the only ad-

vantage to be gained by such a change would be the means of measuring greater angles of elevation and depression, with a double transit-effect for the instrument.

A general description of the writer's Engineer's Theodolite, Fig. 75, has already been given, but the diagram illustrating

Fig. 148.

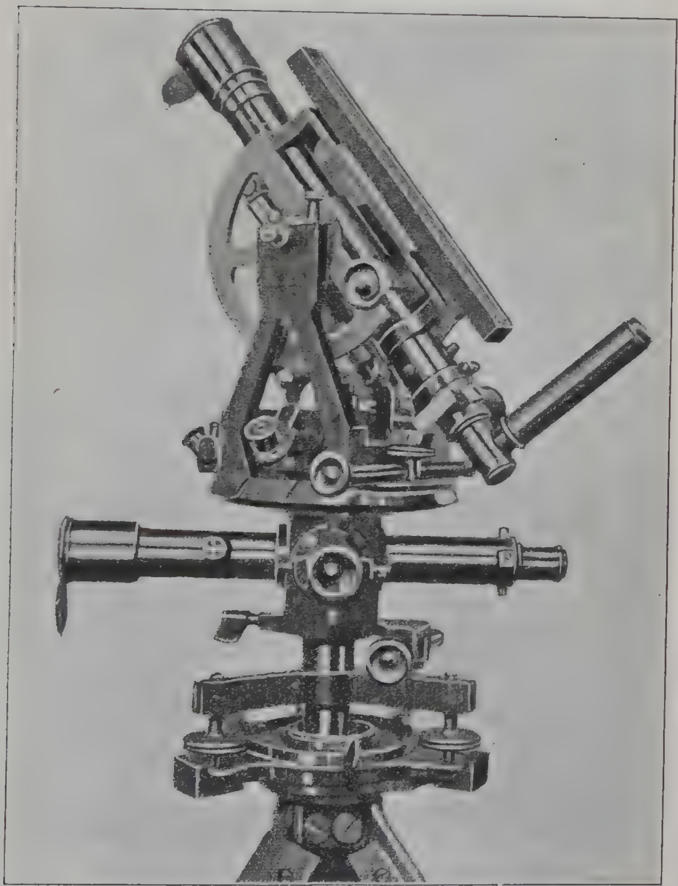


Hoskold's Engineer's Theodolite, Improved, with Circular Compass.

that description does not represent the instrument as now introduced with the ultimate alterations and improvements. Nevertheless, the same general type has been preserved. The four new diagrams, Figs. 147, 148, 149 and 150, exhibit the instrument in different positions, and present all the details of the exterior construction. A very important alteration shown in

Fig. 147 is the tubular or cylindrical bearings, with circular flanges screwed to each exterior side of the lower vertical axis. This arrangement enables the ends of the lower horizontal axis to be suspended in collars between adjusting screws, further from the center of the optical axis of the telescope; and so ef-

Fig. 149.



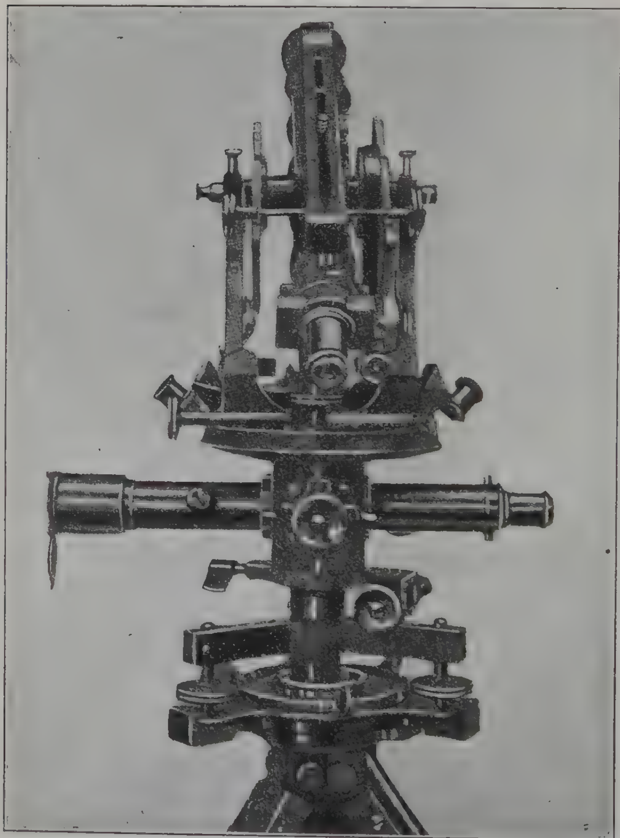
Hoskold's Engineer's Theodolite, Improved.

fectually prevents any possible lateral springing or vibrating effects.

Another important addition is the micrometer, the divided circle or head of which is seen at the eye-end of the upper telescope, Fig. 150. This divided head is attached to a finely-cut screw

working in a metal frame which carries the spider's line index, over the divided comb, placed in the micrometer-box and in the focus of the telescope. There is nothing new in this appendage; still, it is exceedingly useful and important in measuring small angles down to single seconds, and by estimation to the

FIG. 150.



Hoskold's Engineer's Theodolite, Improved.

half of that quantity, and consequently any distance within the range of the telescope may be measured with the greatest facility and accuracy. The simple trigonometrical formula required to effect the calculation of the distance has already been given.* Fig. 148 shows the manner of mounting the circular

* *Trans.*, xxix., 980, February, 1899.

magnetic compass on top of the telescope. When not so required it may be replaced by the long-trough magnetic compass, the needle of which has an arc of only a few degrees—as seen in Fig. 150; or a long spirit-bubble may be inserted in place of the trough-compass, if required.

The circular compass, Fig. 148, contains a magnetic needle with a vernier mounted at each end reading to 15″ of arc. When a magnetic bearing is not required so fine, a plain needle is provided to take the place of the one with verniers. The plain sights of this compass are made very short and in pairs, placed at each side of the compass-box; that is to say, a fine sight and an open one. The open sight is filled with glass, and cross-lines are cut upon it. The sights are hinged on a pin or axis, and can be turned down.

Angleometer.—The instrument of Fig. 76* is one of the most convenient and efficient for measuring angles of elevation to the zenith or depression to the nadir; and consequently, as previously noted,† it is well adapted for general mine-surveying.

Precision of Mine-Theodolites.—Mr. Stanley says:‡ "I do not think mine-surveying so exact as surface." He advances no reason for such a supposition, but possibly is thinking of trigonometrical surveys; neither is it clear whether he attributes the inexactness to systematic carelessness on the part of underground surveyors, or to inferiority of the instruments employed. As the writer's paper on this subject has already mentioned, he proved§ more than thirty years ago that when underground surveys are conducted in a proper manner, with the use of modern instruments of the theodolite class and good line measurers, as much accuracy can be obtained in an underground survey as in similar, though much less difficult and inconvenient, operations on the surface.

---

* *Trans.*, xxix., 969.

† *Trans.*, xxix., 971, February, 1899.

‡ *Trans.*, xxix., 940, October, 1898.

§ *A Practical Treatise on Mining, Land and Railway Surveying, Engineering*, etc., H. D. Hoskold, London, 1863.

Notes on Mine-Surveying Instruments, with Special Reference to Mr. Dunbar D. Scott's Paper on their Evolution,* and its Discussion.†

BY BENJAMIN SMITH LYMAN, PHILADELPHIA, PA.

(Canadian Meeting, August, 1900.)

SYNOPSIS.

SURVEYORS are much indebted to Mr. Scott for so vigorously attacking the subject of the origin and history of mine-surveying instruments, the compass, the telescope, the transit and other apparatus. He is not afraid of the dark, nor yet foolishly bashful in broad daylight. He does not recoil from the obscurities of the earliest times and the most difficult historical points; and, with commendable public spirit, he makes his own invention known to his fellow-workers, and challenges their criticism. He has, moreover, elicited the praiseworthy emula-

* *Trans.*, xxviii., 679. † *Trans.*, xxix., 931, and xxx., 783.

tion of Mr. Hoskold. They both quote from rare old books, two or three of which are to be found in our great Philadelphia and New York libraries, enabling us to ascertain yet a few facts that bear in an interesting way on the origin of the instruments and of some of their essential parts.

I. Ancient History.

Accepted Fables.—Mr. Scott and Mr. Hoskold dip into early Oriental history, but cite only authorities that are antiquated without being ancient. Our few, but very learned Philadelphia Assyriologists and Egyptologists declare they have little faith in the existence of any Assyrian or Egyptian surveying instruments. Proclus, about A.D. 450, in his history of geometry before the time of Euclid, begins with what Prof. A. de Morgan* justly characterizes as "absurd stories:" how the Egyptians invented geometry, or surveying, as a means of recovering landmarks destroyed by the annual Nile floods, and Thales (say 600 B.C.) brought the knowledge to Greece. The oft-repeated tale has so little internal evidence to give it any probability in the eyes of a practical surveyor, that it is surprising to see it approvingly cited from Alfarabius, the famous Arabian scholar of the 10th century, by Jakob Koebel in his *Geometrey von Künstlichem Feldmessen*, the book referred to by Mr. Brough (see the New York Astor Library copy of 1593). When we consider that the doubtless far more highly enlightened Japanese did little or nothing in the way of precise surveying until about 100 years ago, and then with some knowledge of European methods, and even much later were mostly contented with mere sketch maps of the roughest kind; and that it has been the same with the decidedly more advanced Chinese, except for the mapping introduced by the Jesuit missionaries; we may well doubt whether those early ancients accomplished anything better, or used for the purpose any instruments of precision.

Babylonian Mapping.—That doubt is fully confirmed by Fig. 151,† a photographic copy of the best Babylonian map that has yet been discovered, a map of the world, not newer than about 650 B.C., a very rude affair indeed, that could have required no

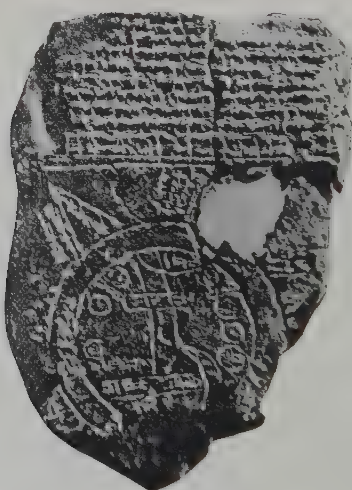
* Smith's *Dictionary of Greek and Roman Biography*, under *Eucleides*.

† Copied from Prof. Paul Haupt's paper in *Ueber Land und Meer*, Dec., 1895, vol. lxxiii., No. 15, p. 348.

instruments of precision beyond the blunt-pointed dividers with which the outside concentric circles, representing the ocean, were drawn on the clay tablet.

Prof. Haupt explains that the points or triangles projecting from the outer circles are marked as islands, and appear to have been originally seven in number. To the left of each island its distance is exactly given, and to the northeastern one is added: "Six hours the sun is not seen." The smaller circles indicate cities of the Euphrates region. The two long parallel curved lines from above downwards are for the Euphrates; and the long parallelogram crossing it is Babylon, on both banks.

FIG. 151.



Babylonian Map-Tablet, about ½ Full-size.

Plainly, no great cartographic skill is here displayed; and it is hard to believe that even rude angle-measuring surveying-instruments could at that time have been in use in that country.

First Surveying.—Undoubtedly, however, land was much earlier measured by rods or cords; and that must have been the beginning of land-surveying. Perhaps the earliest allusion to land-surveying in any language is where Homer, about 900 B.C.,* compares the zeal and vigor of the Greek and Trojan critical battle at the rampart near the ships to the eagerness of a contest between two men, measures in hand, over the boundary that

* *Iliad*, xii., 421–426.

is to divide land that had been held in common. He makes it very evident that the rude surveying of those days left much to mere opinion as to the equitable division of a piece of ground, and that there was nothing like an authoritative county surveyor at hand to settle the dispute. Closely rendered, the passage says:

> As two men over bounds will stiffly strive
> With rood in hand upon a common field,
> And in a narrow plot claim each his share:
> So battlements part these; but they, atop,
> Smite hard before each other's breast the targe
> Well-orbed of oxhide, or the buckler light.

II. Compass.

Chinese Invention.—The invention of the compass has been claimed for the very early Chinese; but von Moellendorff, an excellent authority, declares* that the wet compass has not been proved to exist in China before our 12th century; and that the dry compass was introduced there from Japan, and to Japan from Europe.

Marco Polo.—As for the introduction of the compass into Europe by Marco Polo, mentioned by Mr. Scott, it is not necessary to do more than quote a single sentence from Yule, the highest authority in regard to Polo. He says†: "Respecting the mariner's compass and gunpowder I shall say nothing, as no one now, I believe, imagines Marco to have had anything to do with their introduction."

First European Compasses.—The use of the compass, if really first invented in China, appears, then, to have quickly spread through Europe, according to the early history of the compass in Europe as given pretty thoroughly in *Nature*, by "K.,"‡ and by Wm. Chappell.§ Chappell shows that the earliest European mention of the compass is by Alexander Neckham, an English monk and writer of elegant Latin in the 12th century, who was born about 1150 and died in 1227. Neckham speaks of the compass in his treatise *De Utensilibus*, and yet more clearly, as a thing already in common use, in another treatise, *De Naturis Rerum*. He describes it, not as floating in water, but as turning

---

* *Zeitschrift der Morgenlaendischen Gesellschaft*, 1881, vol. xxv., p. 76.

† *The Book of Ser Marco Polo*, vol. i., Introduction, p. clvi., 1871.

‡ Vol. xiii., Apr. 27, 1876, p. 523.

§ Vol. xiv., June 15, 1876, p. 147.

on a pivot without any special box for it. That seems to show that it was not introduced from China; and, rather, the floating form, soon after common in Europe, was perhaps first carried thence to China. The earliest previously known European mention of the magnetic needle was in the poem called the *Bible of Guiot de Provins*, composed in the 13th century, where a rude floating compass is clearly indicated. The *Encyclopædia Britannica* also cites Cardinal Jacques de Vitry's *History*, written about 1218, as speaking of the magnetic needle as "most necessary for such as sail the sea." A little later, frequent allusions to it occur, and before the middle of the 13th century, as a generally well-known implement. Already, about 1597, Wm. Barlowe denounced "the lame tale" that Flavio Gioja of Amalfi about 1302 invented the compass as "of very slender probabilitie." But the tale persisted until the present century; and, against the claims of the French to the invention of the compass, based on the fleur-de-lis upon it, the answer is made that Gioja "decorated the north end of the needle with that flower in compliment to his own sovereign, who bore it in his arms, as being descended from the royal house of France."

Early Knowledge of Variation.—According to "K.," a Latin letter ascribed to Peter Adsiger, 1269, speaks plainly of the variation of the compass, or magnetic declination. The dip of the needle was, according to "K.," first discovered as early as 1576 by Robert Norman, a nautical-instrument maker at Wapping, near London; and in the early part of the next century the variation of the declination was clearly ascertained, and by Bond, a teacher of navigation in London, attributed to the motion of two magnetic poles of the earth.

Plotting with the Compass.—The ordinary and occasional extent of the diurnal changes of the declination seems hardly to be familiarly known to those geometers who imagine that it is exquisite nicety to plot compass-notes with the help of the very compass used in the field-work, instead of simply using a protractor. Aside from the delay required by the vibrating needle and the possible influence of the friction at the centerpin of a compass not in the very best condition, the daily change of the declination is very notable. The declination was found by Burt in July, 1839,* to change within seven hours and a half

* See his *Key to the Solar Compass*, 1858, p. 27.

sometimes as much as 20 minutes, sometimes only two minutes; but the average of his 18 consecutive days of three observations daily is 14 minutes of change in the same 7½ hours. A. Beyer,* as cited by Combes,† found the needle to vary 30 minutes between noon and midnight, June 4, 1736. I have myself seen a change of about 30 minutes in 14 hours, in Cape Breton. Plainly, if the plotting of a note should not happen to be at a moment when the variation was the same as it was at the time of making the field observation, the plotting would have an error that might be important. On the other hand, in using the simple protractor, there should be no occasion for notable error, leaving merely the original and necessarily inherent errors of the compass in the field, that more or less balance one another.

Hanging-Compass.—It is not a little surprising to learn from Messrs. Hungerford's and Johnson's contributions to the discussion that the hanging-compass has been found on the whole not only practicable, but the most convenient instrument for surveying tortuous, steep, narrow underground workings in Virginia. One would have thought that a compass on a sufficiently small tripod would be not only more satisfactory in result, but more expeditious in use, than apparatus that requires so much circumstance as driving in nails, stretching a cord, hanging up the compass and waiting for the cord vibrations to diminish enough to make it safe to loosen the needle. We have been accustomed to smile, perhaps too superciliously, at this old-world method, and to think its users, even the professors at Paris and Freiberg forty years ago, were one or two hundred years behind the times; with their *gradbogen*, too, and with their square compass (*boussole carrée*), with its telescope at one side and their consequent ingenious elaborate computations to obviate the difficulty of the eccentricity of the sight, instead of using simply a lop-sided target.

Supposed Gravitational Error.—Mr. Hoskold argues‡ that the compass is inexact because the plumb-line in India and elsewhere has been found to be affected by the gravitational attraction of neighboring mountain masses or of especially dense

---

* *Gründlicher Unterricht vom Bergbau nach Anleitung der Markscheidekunst.* Altenburg, 1785.

† *Annales des Mines*, 1836, Troisième Série, vol. ix., p. 98.

‡ *Remarks on Mine-Surveying Instruments, Trans.*, xxxi., 40, 41.

neighboring portions of the earth's crust; and that the probable effect was in advance estimated for the extreme case of the Himalayas as likely to be as much as almost half a minute, though it turned out after all to be "much smaller" than the estimate, and in some places quite reversed in direction. He infers that, as the needle hangs upon the top of a centerpin, it should be affected in the same way as the plumb-line. Even admitting that it were so, it is obvious that the very short length from the ends of the needle up to the level of its point of suspension, say a sixteenth of an inch, would make the arc through which the needle swings extremely short, in fact completely invisible, even if its angular amount were half a minute, and even if its direction were at right angles to the length of the needle.

Of course, as the needle is balanced upon the centerpin, one end would be attracted by the gravity of the mountain or dense mass of rock as much as the other end, so that there would be no effect in that way upon the indication of the needle. On one-half of the needle, however, there is a small bit of brass wire to counteract the dip that is different in different latitudes. That minute additional weight would be attracted towards the mountain or dense rocks; but even supposing that the very feèble or infinitesimal attraction is enough to overcome the at best slight friction at the centerpin, and resist the probably far stronger magnetic directive force of the earth (perhaps as much stronger as the weight of a plumb-bob would be compared to the sidewise pull), and that the attraction works at right angles to the longitudinal axis of the needle and to the highest computed amount of nearly half a minute, even Mr. Hoskold's vernier on the needle for reading quarter-minutes could scarcely in any single reading appreciate the difference caused.

As mountain masses like the Himalayas are extremely rare, and as their observed effect upon the plumb-line proved to be "much smaller" than half a minute, the error from gravitational attraction upon the needle in any ordinary survey would clearly be quite inappreciable, even if the needle were perfectly precise in its indications. When we consider the well-known fact that the needle for magnetic reasons is liable to vary two or three minutes in one hour, it is evident that in using the needle at all, the consideration of the at most alto-

gether invisible and unmeasurable, and moreover wholly doubtful and certainly incalculable, gravitational effect would be like straining out the gnat while ready to swallow the camel. The same may be said, too, of Mr. Hoskold's other idea of undertaking to read the needle to a quarter of a minute with a vernier!

Merit of the Compass.—The merit of the needle is not the extreme precision of its indication in any single reading; but that it refers at each reading independently, within a very few minutes of arc, to an invariable meridian, so that any errors, whether inherent in the compass, or coming from insufficient care in reading or noting, do not, like the errors of vernier-plate running, swing all the subsequent courses of the survey around. The secular variation can be allowed for, and the diurnal changes, if not roughly corrected by the Coast Survey table,* still tend to balance one another. Indeed, the five-inch compass compares reasonably well for accuracy with excellent ordinary chaining, or even with the yet more exact telescopically read stadia-measurement, or with plotting mechanically on a scale of, say, 400 feet to an inch (not by latitudes and departures computed with five-place or larger logarithms). It is not an instrument capable of the utmost precision for geodetic purposes, for city surveying, for tunnel-driving and the like; but it is extremely useful for other much more numerous, in the aggregate far more extensive, and perhaps, on the whole, more important surveys, where the very nicest precision is unnecessary and would require extravagant expense.

III. TELESCOPE.

Origin.—The common accounts of the origin of the telescope are mostly copied one from another, without the least attempt at any independent critical judgment. There is, however, an easily accessible, very thorough discussion in Dr. Robert Grant's *History of Practical Astronomy*, London, 1852; and a later discriminating one by Dr. David Gill, Astronomer Royal, Cape of Good Hope, in the *Encyclopædia Britannica*, 9th edition (1888), and a briefer notice in *Chambers' Encyclopædia* (1892).

The first discovery of the telescope has been variously attributed to Roger Bacon, before 1294, Giambattista della Porta,

* Given in Heller & Brightly's *Remarks on Surveying Instruments*, 1882, p. 13.

1561, Leonard Digges before 1570, three Dutchmen in 1608, and Galileo in 1609. A careful fresh revision of the evidence will make it clear that Bacon and Porta knew nothing of the telescope, that Digges really did invent and use a reflecting telescope, but that Lippershey, one of the three Dutchmen, was the first to make a refracting telescope, and that Galileo reinvented it.

Roger Bacon.—Two citations in particular from Friar Roger Bacon, "the Admirable Doctor," who died about 1294, have been claimed to show clearly that he had at least a theoretical knowledge of the telescope; but they seem really to apply at best merely to single lenses, and nothing that he says necessarily indicates any combination of lenses.

All the passages have been carefully examined by a very competent critic, Robert Smith, LL.D., in his *Compleat System of Opticks*, Cambridge, 1738. He says that Bacon, in his *Opus Majus*, having described several canons of refraction through a plane and a spherical surface, applies them to the explanation of several appearances (doubtless familiar from the earliest times); such as, why an oar partly in the water appears crooked, and why a coin in the bottom of a basin, hidden from the eye by the side of the basin, becomes visible on pouring in water; and that Bacon then adds a passage which Smith cites in full with its diagrams, essentially to the following effect:

> "If a man should look at letters or any minute objects through the medium of a crystal, or glass, or other transparent body placed upon the letters; and it should be the segment of a sphere of which the convexity is towards the eye, and the eye should be in the air, he will see the letters better and they will appear larger to him; . . . and therefore this instrument is useful to old men and to those that have weak eyes. . . . But if it be the larger segment of a sphere, or but half of one, then, by the sixth canon, there will be an enlargement of the visual angle and an enlargement of the image, but nearness will be lacking, because the place of the image is beyond the object. And therefore this instrument is not so effective (*non ita valet*) as the lesser segment of a sphere."

It is noticeable that the segment rests immediately, flatwise, upon the letters, and there is nothing said of a refraction at both the surfaces. Smith translates "*non ita valet*" by "not so powerful in magnifying," and argues that Bacon showed thereby his ignorance of the real effect of the lens, and consequently never could actually have used one; and adds:

> "As to his theory and applications abovementioned, they are all taken from *Alhazen*, whom he frequently mentions upon other occasions. *Alhazen* is reckoned

to have lived about the year of our Lord 1100 [born at Bassora, and died at Cairo about 1038]. Among his experiments made to confirm his theorems, he expressly mentions that if an object be applied close to the base of a larger segment of a sphere of glass, it will appear magnified; which, as I observed, was fitter for Bacon's purpose than his own lesser segment. He also treats about the appearance of an object through a globe; and says he is the first that found out the refraction of rays into the eye."

The magnifying effect of a glass globe on near objects could, however, scarcely have failed to be noticed long before Alhazen. Indeed, a passage in Aristophanes (*Clouds*, Act II., Scene 1) clearly indicates a common knowledge of burning-glass lenses among the ancient Greeks, 423 B.C., 150 years before the time of Archimedes' mythical exploit of ship-burning with a glass.

But when Bacon uses the words "*non ita valet*," he has just distinctly acknowledged the greater size of the image, and with those words he explains that, after all, owing to the greater distance of the image, the instrument is less effective, meaning apparently not in magnifying power, but in definition, and therefore less useful in the general result. The increased thickness of the glass would add to the spherical and chromatic aberrations, and with the impure glass of the 12th century (when "uncolored" glass was greenish, with many bubbles), the greater thickness would to some extent bedim the view; and the obscure result might conceivably have been attributed to the greater distance of the image. It looks, then, rather as if Bacon did really try such lenses, large segments of glass spheres of some size.

The practice of laying such a lens flatwise immediately upon letters, for the convenience of old or weaksighted men, may well have been the first step towards the invention of spectacles, a discovery destined to be of such immense importance to elderly people, and almost equivalent to a prolongation of their lives by many years. Indeed, Smith, although regarding Bacon's words as mere theoretic speculations, and incorrect ones, considers, possibly with some patriotic feeling, that they gave the first hint towards the invention; and in corroboration makes certain citations in other quarters, showing that spectacle-glasses were invented between 1285 and 1300. For instance, Friar Jordan de Rivalto, who died at Pisa in 1311, is said to have written, in a book of sermons in 1305, that it was not twenty years since the art of making spectacles was found out;

and an Italian manuscript of 1299 in Redi's library says they had lately been invented for the convenience of poor old men with failing power to read. Friar Alexander de Spina, who died at his native city of Pisa in 1313, is said by a Latin chronicle there to have first published spectacle-glasses between 1280 and 1311, not as his own invention, but the discovery of somebody else who would not make them public. Smith not unreasonably conjectures that other "close man" to have been a friar; "and that these monkish men, and Jordan amongst the rest, had this invention whispered amongst themselves, before it was publick; and that they all had the first hint thereof from our country-man *Frier* Roger Bacon."

The passage in the *Opus Majus* specially used to support the claim that Roger Bacon combined lenses into a telescope says:

> "We can give such figures to transparent bodies, and dispose them in such order with respect to the eye and the object that the rays shall be refracted and bent towards any place we please. So that we shall see the object near at hand or under any angle we please. And thus from an incredible distance we may read the smallest letters, and may number the smallest particles of dust and sand, by reason of the greatness of the angle under which we see them."

Smith argues that the passage indicates that Bacon

> "did not think of performing these problems by a single portable instrument like a telescope, but by fixing up several glasses in proper places at large intervals from one another [much as he had in the foregoing chapter explained that mirrors might be arranged so as to multiply a single soldier into an army in appearance]; which would certainly prove ineffectual. . . . Mr. *Molyneux* says it is manifest he knew what a concave and a convex glass was. But this does not appear from the passage there cited, nor from any other that I have yet met with. . . . In short, the author speaks only hypothetically, saying that glasses may be figured, and objects may be magnified so and so; but never asserts one single trial or observation upon the sun or moon (or anything else) though he mentions them both. On the other hand he conceives some effects of telescopes that cannot possibly be performed by them."

It seems that the passage just quoted from Bacon might refer merely to the possible or conceivable change of direction in rays by means of a prism, or perhaps of a combination of prisms (though the words do not clearly indicate that any combination is meant), and to the enlargement possible by means of the segment of a sphere, or rude lens, whose use had been already described, and whose effect, then so novel, may naturally have been set forth in language that would now seem ex-

aggerated. The words do not necessarily imply a combination of more than one glass at a time. There is, then, no sufficient reason to believe that Roger Bacon ever used a telescope, or even any nearer approach to a spectacle-lens than a very thick spherical segment of impure glass applied close to the letters read.

Porta.—A citation from Giambattista della Porta's *Magia Naturalis*, printed in 1558–89, in the XVIIth Book, apparently published in 1561, contains expressions that have been taken to prove that he used a telescope; but it has also been said that grave doubts have been thrown upon Porta's knowledge and originality by such high authorities as Kepler and Poggendorff. All Porta's claims to the invention of the telescope have, to be sure, their foundation in what Kepler says and quotes of Porta in a charming, generously appreciative letter to Galileo, published in 1610, and written after receiving in Galileo's *Nuncius Sidereus* the account of the re-invention of the telescope and the first astounding telescopic astronomical discoveries, the four moons of Jupiter, the diversified appearance of the moon's surface, the distinctly orbicular shape of the planets, the tenfold increase of visible stars, the resolution of nebulæ in the milky way into stars, and the like.

The common short notices give so imperfect and inconclusive and apparently so inaccurate an account of Porta's statements and of Kepler's comments on them, and even Kepler himself so seems to misinterpret Porta, and the original is so difficultly accessible to most of our members, that it is probably worth while to give here the whole passage from Kepler's letter; the more so, as it shows in a striking light how far even the ablest astronomers and physicists of those times had been from realizing the possibility of anything like a telescope, simple and natural as such an application of the well-known laws of optics seems nowadays. Kepler appears to say, in pretty literal translation (and for greater certainty the more essential part of the original Latin is given below):*

"Incredible to many seems the undertaking of so effective a spyglass; but impossible or new by no means is it; nor did it lately first proceed from the Dutch,

* *Opere di Galileo*, Florence, 1892, vol. iii., p. 108:
"Incredibile multis videtur epichirema tam efficacis perspicilli, at impossibile

but already a number of years ago it was published by Io. Baptista Porta in Natural Magic, Book XVII, Chap. X, On the Properties of the Crystal Lens. And that it may appear that not even the arrangement of a concave and a convex lens is new, come, let us bring forward the words of Porta. He writes thus:

"*With the eye placed in the center, behind the lens, whatever was remote you will see so near that you would seem to touch it with the hand, or that you will recognize friends that are very distant: letters of an epistle placed at a due distance you will see so large that you can clearly read: if you incline the lens, so as to look at the epistle obliquely, you will see the letters sufficiently large to read them even at a distance of twenty paces:* and if you know how to multiply the lenses, I doubt not but that you would see the smallest letter at a hundred paces, *so that from one into another the characters may be rendered larger. Let defective sight use glasses according to the quality of the sight. Whoever should understand how to make that adaptation rightly will get a secret that is not small. Concave lenses make whatever is distant to be seen very clearly, convex ones what is near, wherefore you can enjoy them according to their adaptation to your vision. With a concave lens you see small things at a distance, but distinctly; with a convex one, you see near things larger, but indistinctly:* if you know how to arrange each rightly, *you will see both distant and near things larger and clearly. Not a little aid have I given to many friends who saw both distant things dimly and near ones indistinctly, so that they saw everything most perfectly.* So much from Chap. X.

"In Chapter XI he makes a new title on glasses with which beyond all thought any one can see very far; but he so involves the demonstration (which he even admits), that you would not know what he says, whether he is speaking of transparent lenses, as hitherto, or indeed adds an opaque smooth mirror: of which even I myself have one in mind, which shows remote things, with no difference of distance, in very great size, and therefore near and moreover proportionally enlarged, with as much clearness as can be hoped for from a mirror (which necessarily gives a dim color).

"When to this part of Porta's book I saw the complaint prefixed at the beginning of Chapter X, that *of concave and convex lenses and glasses, so greatly necessary for human uses, no one had yet brought forward the effect or the explanations,* I undertook that work six years ago in the Optical part of my Astronomy, so as to set forth with a clear geometrical demonstration what occurs in simple lenses.

---

aut novum nequaquam est; nec nuper a Belgis prodiit, sed tot iam annis antea proditum a Io. Baptista Porta, Magiae naturalis libro XVII, Cap. X, De Crystallinae lentis affectibus. Utque appareat, ne compositionem quidem cavae et convexae lentis esse novam, age verba Portae producamus. Sic ille:

"*Posito oculo in centro, retro lentem, quae remota fuerint adeo propinqua videbis, ut quasi manu ea tangere videaris, ut valde remotos cognoscas amicos: literas epistolae in debita distantia collocatae, adeo magnas videbis, ut perspicere legas: si lentem inclinabis ut per obliquum epistolam inspicias, literas satis maiusculas videbis, ut etiam per viginti passus remotas legas:* et si lentes multiplicare noveris, non vereor quin per centum passus minimam literam conspiceris, *ut ex una in alteram maiores reddantur characteres. Debilis visus, ex visus qualitate specillis utatur. Qui id recte sciverit accommodare, non parvum nanciscetur secretum. Concavae lentes, quae longe sunt clarissime cernere faciunt, convexa propinqua, unde ex visus commoditate his frui poteris. Concavo, longe parva vides, sed perspicua; convexo, propinqua maiora, sed turbida:* si utrumque recte componere noveris, *et longinqua et proxima maiora et clara videbis. Non parum multis amicis auxilii praestitimus, qui et longinqua obsoleta, proxima turbida conspiciebant, ut omnia perfectissimo contuerentur.* Haec Capite X." Etc.

"There are to be seen there in Chapter V, where I demonstrate what pertains to the manner of seeing, on fol. 202, representations of a concave and convex lens united in a diagram, plainly in the same way that they are customarily joined together to-day in the common tubes [telescopes]. If the reading of Porta's Magic did not give occasion to this contrivance, or if some Dutchman with instruction from Porta himself did not, when the injunctions of silence had been dissolved by the death of Porta, multiply the manufactured instrument to numerous specimens, in order to make merchandise for sale, certainly this very figure at folio 202 of my book could suggest the construction to a curious reader, especially if he joined the reading of my demonstrations with Porta's text.

"Still, it is not incredible that clever gravers among an industrious people, who use lenses for looking at the minute details of engraving, should by chance, too, fall upon this device, in variously associating convex lenses with concave, in order to select the combination that best suits their eyes.

"I do not say that to lessen the praise of the inventor, whoever he was. I know how great the difference is between theoretical conjectures and ocular experience; between Ptolemy's discussion about the Antipodes and Columbus's discovery of the new world: so, too, between the commonly circulated two-lensed tubes and, Galileo, your contrivance, with which you have bored through the very sky: but I am striving here to create for the incredulous a belief in your instrument.

"Confession should be made, that at the time I attacked the Optics, when the Emperor repeatedly asked me about the above-written artifices of Porta's, I derogated faith in them as much as possible. Nor is it wonderful: for he manifestly mixes incredible things with probable ones; and the title of Chapter XI, with the words *To look forth extremely far, beyond all thought*, seemed to involve an optical absurdity: as if vision were made by emission, and lenses sharpened the rays of the eye, so that they could penetrate more remotely than if no lenses were used: or if, as Porta acknowledges, vision were made by receiving; as if then the glasses conciliated or increased the light for seeing things: while this rather was true, those things that did not send any light far enough to reach our eyes and so be seen would never be detected by any glass.

"Besides, I not only believed that the air was thick and of a blue color, so as at a distance to cover up and confuse the minute parts of visible things; and, as that was certain, I saw it was vain to expect from a spyglass that it should strip off this substance of the intermediate air from visible objects; but also, in regard to the celestial essence itself, I suspected it was such a thing that it could hinder us, if we should very greatly increase the body of the moon into something immense, from being able so well to recognize the small particles of the moon in their purity apart from the extremely deep celestial matter.

"For those reasons, then, I abstained from undertaking any contrivance, and besides there were other things that hindered.

"But now, as you deserve, most accomplished Galileo. I commend your activity; for you, setting aside all mistrust, have applied yourself to direct ocular experiments; and now that the Sun of truth has by means of your discoveries risen, you have dispelled all those hobgoblins of waverings along with the night their mother; and have shown by deeds what could be done."

It may be overboldness to undertake to question Kepler's interpretation of Porta's words; but it does clearly appear that he misunderstood Porta's application of the word *componere*.

Even Homer sometimes nods. Porta is speaking throughout only of the use of simple lenses, or spectacle-glasses, concave and convex, and their use for near and far sight, with perhaps some exaggeration; and when he says "*si utrumque recte componere noveris*," he means: if you know how to put together, or join, or arrange each kind, not (as Kepler imagines) with the other kind, but with its appropriate defect of vision; a suitable concave lens with short sight and a proper convex lens with far sight. That understanding is corroborated by what he immediately goes on to say, of aiding many nearsighted and farsighted friends, so that they saw both distant and near things distinctly. Obviously, each friend could have had only one of the two defects of sight, nearsightedness or farsightedness, and so must have used only one kind of lens for it. Porta at first certainly speaks of the use of a single lens, and when he mentions, perhaps only hypothetically, the greater effect from multiplying lenses, he seems to mean increasing the number of lenses of one kind, with power thereby enhanced. All the rest appears to be about single lenses or spectacle-glasses.

Kepler's citations from Porta, however, apparently convinced both the friends and opponents of Galileo at that time that Porta, and not the Dutchman, had been the first inventor of the telescope; and the accounts of Porta down to the present day seem to be based simply upon Kepler. Even Grant and more clearly the *Encyclopædia Britannica* quote Porta as speaking distinctly of joining together concave and convex glasses; whereas his words, as we have seen, do not by any means justify that interpretation, though Kepler may be excusable for so misunderstanding them at the subsequent first announcement of the refracting telescope.

That Porta was not incapable of exaggeration is now evident from a citation that Franciscus Sitius, a contemptuous opponent of Galileo, makes from Porta's book, arguing the obvious absurdity of the idea that such a man as Galileo should discover what the great Ptolemy with equal opportunity had not seen. The passage occurs in Sitius's essay printed with Galileo's works, Florence edition, 1892, p. 238. Porta there tells how Ptolemy had a spyglass that enabled him on the Pharos tower at Alexandria to see a ship at sea 500 stadia off (about 60 miles —not 600, as Smith has it). The curvature of the earth's sur-

face would alone require the tower to be about 2000 feet high to see a ship sixty miles off. Hence it is equally plain that not only were the inventors of the telescope forestalled by nearly 2000 years, but Eiffel himself was immensely outdone.

Furthermore, it is now perfectly plain from the European experience at the time of the Dutch invention, scarcely fifty years later than Porta, that a refracting telescope used by many friends, and evidently made no secret, would not have escaped rapid transmission through Europe. Beyond question, then, Porta knew absolutely nothing of the telescope.

Digges.—The next supposed, and really much more circumstantial mention of the telescope is in the book published in 1571 under the title: *A Geometrical Practise named Pantometria . . . framed by* Leonard Digges *Gentleman, lately finished by Thomas Digges his sonne.* There is a copy of the book in the Philadelphia Library. The book is 7½ inches by 5½ and ¾ inch thick besides the leather covers. It is unpaged, and printed mostly in black letter, with interspersed italics and letters like our modern so-called antique letters. There are a number of illustrations. At the end of the volume the son speaks of himself as in his twenty-fifth year. The father is supposed to have died about 1570. An epistle dedicating the work to "Sir Nicolas Bacon, Knight, Lord keper of the great seale of England," speaks of the father's "untimely death" and of the book as one of "certaine volumes that he in his youthe time long sithens had compiled in the English tongue." The preface among other things says:

"Archimedes also (as some suppose) with a glasse framed by revolution of a section Parabolicall, fired the Romane nauie in the sea comming to the siege of *Syracusa.* But to leave these celestiall causes and things doone of antiquitie long ago, my father by his continual paynfull practises, assisted with demonstrations *Mathematicall* was able, and sundrie times hath by proportionall Glasses duely situate in conuenient angles, not only discouered things farre off, read letters, numbered peeces of money with the very coyne and superscription thereof, cast by some of his freends of purpose vppon Downes in open fieldes, but also seuen myles of declared what hath been doon at that instante in priuate places: He hath also sundrie times by the Sunne beames fired Powder, and dischargde Ordinance half a mile and more distante, whiche things I am the boulder to reporte, for that there are yet liuing diuerse (of these his doings) *Oculati testes*, and many other matters farre more straunge and rare which I omitte as impertinente to this place."

Evidently Archimedes's "glasse" was a mirror; and the

word "glasse" is used in the same way in the 21st Chapter, where it is described

"How ye may most pleasantly and exactly with a playne glasse from an highe cliffe, measure the distance of any shippe or shippes on the sea as followeth. The best kinde of glasse for this purpose is of steele finely pullished, so that the Superficies thereof be smoothe, neyther convexe nor concave, but flatte and playne as may be possible," etc.

At the end of the same 21st Chapter is the principal account of what has been taken to be the telescope. The whole passage is as follows, and in it the same use of the word "glasse" for mirror, and of the word "playne" in distinction from convex and concave is to be observed:

"Thus muche I thought good to open concerning the effects of a playne Glasse, very pleasant to practise, yea most exactlye seruing for the description of a playne champion countrey. But marveylouse are the conclusions that may be perfourmed by glasses concave and convex of circulare and parabolicall fourmes, vsing for multiplication of beames sometime the ayde of glasses transparent, whiche by fraction should vnite or dissipate the images or figures presented by the reflection of other. By these kinde of glasses or rather frames of them, placed in due angles, ye may not onely set out the proportion of an whole region, yea represent before your eye the liuely ymage of euery towne, village, &c., and that in as little or great space or place as ye will prescribe, but also augment and dilate any parcell thereof, so that whereas at the firste apparance an whole towne shall present it selfe so small and compacte together that ye shall not discerne any difference of streates, ye may by applycation of glasses in due proportion cause any peculiare house, or roume thereof dilate and shew it self in as ample fourme as the whole towne firste appeared, so that ye shall discerne any trifle, or reade any letter lying there open, especially if the sonne beames may come vnto it, as playnly as if you wer corporally present, although it be distante from you as farre as eye can discrye: But of these conclusions I minde not here more to intreate, hauing at large in a volume by it selfe opened the miraculous effectes of perspectiue glasses. And that not onely in matters of discouerie, but also by the sunne beames to fire, pouder, or any other combustible matter, whiche Archimedes is recorded to haue done at *Syracusa* in Sicilie, when the Romane Nauy approched that Towne. Some haue fondly surmised he did it with a portion of a section Parabolical artificially made to reflect and vnite the sonne beames a great distance of, and for the construction of this glasse take great paynes with highe curiositie to write large and many intricate demonstrations, but it is a meere fansie and vtterly impossible, with any one glasse whatsoeuer it be to fire any thing, onely one thousand pase off, no though it were a 100 foote over, marry true it is, the Parabola for his small distance, most perfectly doth vnite beames, and most vehemently burneth of all other reflecting glasses. But how by application of mo glasses to extende this vnitie or concourse of beames in his full force, yea to augment and multiply the same, that the farder it is caried the more violently it shall pearse and burne. *Hoc opus hic labor est*, wherein God sparing lyfe, and the tyme with opportunitie seruing, I minde to imparte with my countrey men some such secretes, as hath I suppose in this our age ben revealed to very fewe, no lesse seruing for the securitie and defence of our naturall countrey, than surely to be mervailed at of straungers."

It is evident that he writes of a reflecting telescope, and not of a refracting one. The "ayde of glasses transparent" therewith is mentioned as only "sometime useful," apparently for the eye-piece, or, as he says, for "multiplication of beames," because, merely, the "fraction should unite or dissipate the images or figures presented by the reflection of the other" glass, or mirror—that is, cause the rays to converge or diverge.

One difficulty in believing that a telescope existed in England before 1571, nearly forty years before the first Dutch telescope, has been to account for its not becoming in all that time widely known and used, whereas the fame and use of the Dutch telescopes ran through all Europe within a few months. The reason may well be that Digges's telescope was a reflecting one, comparatively difficult and costly of construction. Even in Friar Bacon's time, in the depth of the dark ages, a refracting telescope really in use could hardly fail to have been copied, as the spectacle-glasses were, and to have spread through Europe. The last sentence of Digges's account seems also to intimate that the value of even a reflecting telescope for military purposes was fully appreciated, or perhaps over-estimated, and that consequently its use had "ben revealed to very fewe, no lesse seruing for the securitie and defence of our naturall countrey, than surely to be mervailed at of straungers." Digges appears to have had the friendship of very high officials, and the dedicatory epistle to Queen Elizabeth's celebrated Lord Keeper of the Great Seal, Sir Nicholas Bacon, father of the famous Lord Bacon, mentions "the great fauour your lordship bare my father in his lifetime and the conference it pleased your honor to vse with him." It is not impossible that the government may have discouraged the general promulgation of the method of constructing the telescope; just as the first idea in regard to the Dutch telescope was to keep it secret for military uses. At any rate, the younger Digges in his several later books never published the full description of the telescope, according to what he says of "having at large in a volume by it selfe opened the miraculous effectes of perspectiue glasses." The word "perspective" here does not appear to imply transparency, but to be used rather in place of "prospective" or "optical."

In his book called *Stratioticos*, published in 1579, is said to

occur, at p. 359, the statement that his father, "among other curious practices had a method of discovering by perspective glasses set at due angles all objects pretty far distant that the sun shone upon, which lay in the country round about," and that this was by the help of a manuscript book of Roger Bacon of Oxford. The repeated mention of the "due angles" at which the glasses must be set seems to indicate the necessary observance of the angles of incidence and reflection of mirrors, and to be quite inapplicable to the description of the refracting telescope.

We may then safely conclude that Leonard Digges did really use a reflecting telescope; but that the refracting telescope was not yet invented.

Lippershey.—The next telescope was the Dutch refracting telescope of 1608. Its origin was fully set forth so long ago as 1831, in Vol. I. of the *Journal of the Royal Institution*, by Dr. G. Moll, of Utrecht, in his account of the already deceased Professor Van Swinden's researches into the government archives at the Hague. They fully established the fact that the spectacle maker, Hans Lippershey, of Middelburg, was the maker of the first refracting telescope, previous to Oct. 2, 1608 (in the midst of the 80 years' war); for the government on that day considered his petition for a patent on the instrument, or an annual pension, in case the government should require the exclusive use of the invention. Less accurate investigations in 1655 gave the credit to another spectacle-maker named Zacharias Jansen, in 1610; who, according to those investigations, would appear to have invented the compound microscope about 1590; though Fontana claims to have invented it in 1618, and Huygens's investigations make it probable that it was first invented by Drebel, a Dutchman, in London, about 1620. Jacob Adrianzoon, a learned mathematician, also called James Metius (called Metius from a student-nickname that clung to a brother of his through life), applied to the government on October 17, 1608, for a patent on a telescope of his invention as powerful as the one lately offered to the government by a spectacle-maker of Middelburg—that is, evidently by Lippershey. Adrianzoon claimed to have made his discovery independently, partly by theory and partly by accident, within the previous two years. He was not encouraged by the government, and, apparently in

disgust, he never made his method public. The government, oddly enough, was not at first fully appreciative of Lippershey's wonderful, epoch-making discovery, or at least not satisfied; and, on October 6, 1608, required of him a spy-glass made of rock-crystal that could be used with both eyes, at the price of 300 florins, instead of the 1000 florins he had at first demanded; and exacted a promise from him to make no such instruments without the consent of the States. He accordingly supplied them with such a binocular on the 15th of the next December; and they ordered two more like it, and paid him 900 florins, or about $360, for the three (not for one, as some say); but they refused the patent, because the invention had already become known to many.

Lippershey's first discovery happened by accident, as the common story goes; that is, he had the intelligence to perceive the bearings of an accidental observation. It is said that he chanced to look through two spectacle lenses, one in each hand, towards a neighboring steeple, and was astonished to find how near and distinct the weathercock became. It has been urged against the story that it also mentions that the weathercock became inverted, as it would be if seen through two convex lenses; whereas the Dutch telescope was not inverting, but was made with a convex and a concave lens. It is, however, more probable that the two lenses in his hands should be alike, and not in the least improbable that they should both be convex. Indeed, the effect of two concave lenses would scarcely be particularly noticeable, as being merely of double the power and suited to doubly nearsighted eyes. It is the remarkable difference in the effect of two convex lenses at an accidentally suitable distance apart that would have been especially striking. He evidently was a very intelligent, ingenious man, and doubtless was as ready, either by theoretical or by experimental investigations, to obviate the inconvenience of the inversion as he later was to prepare a binocular for the exacting legislators. The inverting telescope accordingly remained in abeyance until Kepler suggested its advantages in 1611, and Scheiner constructed one in 1617, and published it in 1630.

Lippershey's first telescope was, on the 2d of October, 1608, in the possession of Maurice, Prince of Orange and Count of Nassau, the head of the Dutch government. At first it was

thought to keep the invention secret for military purposes; but it soon got abroad, and within a few months its fame (mainly as a curious toy, to be sure) had gone all over Europe.

Galileo.—The account of Galileo's reinvention of the telescope, as related by Moll from Galileo's own writings, and essentially repeated by Grant and other writers, shows they had never seen one or two letters of Galileo that were not published until 1847, and that throw a little additional light on the matter.

The date of the reinvention has never been exactly fixed, but was long taken to be in May, or even in April, 1609; owing to Galileo's first public mention of it, in his *Nuncius Sidereus*, published early in March, 1610, as having occurred "nearly ten months ago" (*mensibus abhinc decem fere*). In his rough draft he had written "eight months," as may be seen in the *fac simile* in the recent, yet unfinished, Florentine edition of his works (1892, vol. iii.); and the change was perhaps due to delay in printing, or to imperfect recollection, or to a desire to use a round number, or to a combination of more than one of these causes. But in his letter of August 29, 1609, to B. Landucci, first published in the Florentine edition of Galileo's works, of 1847, vol. vi., p. 75, he gives the time as "about two months ago" (*sono circa a due mesi*); showing it clearly to be not earlier than June, 1609.

That letter and the *Nuncius Sidereus* and Galileo's *Il Saggiatore*, published in 1623, relate the circumstances in a sufficiently concordant manner, each account giving some points omitted by the others. He says, then, that about June, 1609, while he was professor of mathematics at Padua, but on a visit to Venice, rumors came that a spyglass made by a Dutchman had been presented to Count Maurice which made very distant things seem very near, so that a man two miles off could be distinctly seen; "and nothing more was added" (*nè più fu aggiunto*). The rumors were believed by some, and not by others; but in a few days were confirmed by a letter to Galileo from a French noble, James Badovere, at Paris. On Galileo's return from Venice to Padua these rumors set him to trying to think out the method that could accomplish such results. With his knowledge of optics, feeling sure it could not be with a single lens, nor with two similar lenses, he that same night concluded

it must be with a convex and a concave lens. The next day he took a piece of leaden pipe and put two such lenses into it and found he had a magnifying power of three times linear. The same day, he sent word of his success to his friends at Venice, with whom he had been discussing the rumors the day before. He then set to work upon another more perfect telescope, with a magnifying power of nine times linear; and six days later, in compliance with the government's request, he took it to Venice, where it was seen with wonder by the whole senate and all the principal gentlemen of the republic for more than a month together, much to his own fatigue. They climbed up eagerly, even old men, more than once to the top of the highest towers of the city, and descried vessels more than two hours before under full sail they became visible to the naked eye. At length, by the advice of one of his most affectionate patrons, and seeing how useful a thing the telescope would be on sea and land, he freely made a present of it to the Doge in full assembly, on the 25th of August, 1609. The telescope was received with such admiration, that Galileo's professorship was made an appointment for life, and his yearly salary nearly doubled, increased to 1000 florins (about $900), three times what any previous incumbent had received. This warm appreciation of the merits of his discovery among his numerous Venetian friends is of itself full confirmation of his otherwise undoubted statement, that the rumors of the Dutch telescope had been a very insufficient guide to the method of its construction. In his *Il Saggiatore* he argues against the detractions of one of his opponents that, although he claims no great credit for the discovery, yet it is more meritorious to work out by reasoning the method of attaining a result known to be possible, than to hit upon the method and result by accident. To be sure, he might not have thought of making a telescope, had it not been for the rumors of the Dutch one, but merely on the suggestion of those rumored results he worked out the method with nobody's help. He deprecates his opponent's attempt to take away the little merit there might be in his performance.

He made more and more powerful telescopes, up to a magnifying power of not more than thirty-two or thirty-three times linear, about the limit for telescopes of the Galilean kind without achromatic correction, and about a yard in length. But

his chief merit was the immediate application of the telescope to astronomical discoveries that startled the world, especially theologians.

Improvements.

Micrometer and Cross-Hairs.—With the Keplerian telescope first came the possibility of the micrometer, invented by Gascoigne perhaps as early as 1638, when he was only about eighteen years old; and it was seen by Crabtree in 1639, as mentioned in a letter of his to Horrocks.* Flamsteed's *Historia Cœlestis*, Vol. I., records the mutual distances of the Pleiades as given by Gascoigne to seconds in a letter of 22 May, 1639, to Crabtree, distances apparently measured with the micrometer. Twenty years later it was reinvented on the Continent. The micrometer had two straight edges of metal that were by a screw made to approach each other at the focus of the telescope. Hooke suggested using human hairs instead of the metallic edges. Silver wires and silk fibers were used in the early continental micrometers; and Mr. Brough points out that a century later lines on glass or mica were used at the focus. Spider-webs were not applied until David Rittenhouse's invention in 1785, unless Mr. Brough can substantiate his date of 1775.† For in November, 1785, a letter from Rittenhouse was read before the American Philosophical Society, with the following postscript (*A. P. S. Trans.*, 1786, Old Series, Vol. II., p. 183):

> "P. S. The great improvement of object glasses by Dolland [*sic*] has enabled us to apply eye-glasses of so short a focus, that it is difficult to find any substance proper for the cross-hairs of fixed instruments. For some years past I have used a single filament of silk, without knowing that the same was made use of by the European astronomers, as I have lately found it is by Mr. Hirschell [*sic*]. But this substance, though far better than wires or hairs of any kind, is still much too coarse for some observations. A single filament of silk will totally obscure a small star, and that for several seconds of time, if the star be near the pole. I have lately with no small difficulty placed the thread of a spider in some of my instruments; it has a beautiful effect; it is not one-tenth of the size of the thread of the silkworm, and is rounder and more evenly of a thickness. I have hitherto found no inconvenience from the use of it, and believe it will be lasting, it being more than four months since I first put it in my transit telescope, and it continues fully extended and free from knobs or particles of dust."

---

* Cited by Grant (p. 452) from Sherburne's translation of the *Sphere of Manilius*, 1675, p. 92.

† *Trans.*, xxix., 934.

This distinct statement seems to put at rest Mr. Scott's assertion,* apparently taken from the *Encyclopædia Britannica* (under *Micrometer*), that Troughton was the first to put spider-webs to practical use, on Rittenhouse's suggestion. The *Encyclopædia* also says that they were first suggested, though not used, by Prof. Fontana, of Florence, in 1755.

Rittenhouse's First Telescope.—Mr. Scott adds that Rittenhouse at the time of his invention was "constructing the first American telescope." A diligent search through several biographies and notices of Rittenhouse at Philadelphia, his home, and through papers in the *Transactions of the American Philosophical Society*, Vols. I. and II., has failed to be rewarded by the discovery of the least allusion to any such priority of construction by him; though already at the time of the transit of Venus in 1769 he had shown himself not only a learned theorist but "mechanic enough to make with his own hands an equal altitude instrument, a transit telescope and a timepiece." He appears to have made his own first telescope about 1756, when he was twenty-four years old.

Platinum Cross-Wires.—In 1871 Messrs. Heller & Brightly, of Philadelphia, introduced and published the use of platinum cross-wires $\frac{1}{1000}$ of an inch in thickness, or as thin as ordinary spiders' webs, in the telescopes of engineering transits. The platinum wires obviate the sagging which dampness causes in spiders' webs; and, not being transparent, can easily be seen when the sight is towards a light, say the sun, the north star, or a lamp. (See the Report of the Franklin Institute Committee, December 18, 1871.)

Telescopic Sights.—The possibility of using a telescope for ascertaining with precision the direction of sight, and consequently the application of telescopes to graduated instruments, depend, of course, on the use of two convex lenses, the Keplerian arrangement; for with the Galilean method there is no means of marking a definite and invariable optical axis of the telescope. Here, too, the young Gascoigne, who died at Marston Moor, 1644, in his twenty-fourth year, was the leader, and, already by 1640, he used for the purpose a hair or thread at the focus. It was even claimed in 1675 that he had been the

---

* *Trans.*, xxviii., 698.

first to use a telescope of two convex lenses. At any rate, he was evidently the first to use telescopic sights.

Reflecting Telescope.—Keplerian telescopes, with two convex lenses, were used, then, for astronomical purposes; and were made of enormous length by Huygens, Cassini and others, even up to 300 feet long, and without tubes, and called therefore aerial telescopes. But the spherical aberration, already understood, and especially the chromatic aberration, then unknown, prevented satisfactory definition; and in 1663 James Gregory proposed the reflecting telescope, since called by his name, and was the first to explain completely its construction, though the idea had long been known in a general way. Newton, after his discovering the reason of chromatic aberration, made the first reflecting telescope, except, as we now have reason to believe, Digges's of a hundred years before. Newton made his invention public in 1671.

Achromatic Lens.—Achromatic lenses were first made, it seems, in 1733 by Chester Moor Hall, an English lawyer and mathematician, but he was in independent circumstances and took no special pains to publish his invention or get a patent; and in 1758 John Dollond, of London, made public his successful construction of an achromatic lens, and he obtained a patent on it. The patent was legally maintained notwithstanding the earlier invention by Hall, whose neglect expressly to publish it was severely animadverted upon by the judge.

The difficulty of making satisfactory flint glass was still an obstacle to the construction of large astronomical achromatic lenses, until Guinand, a humble Swiss watchmaker, after seven years of experiments succeeded in 1790 in producing by secret methods large masses of flint glass free from striæ. Fraunhofer induced him to remove with the secret to Munich in 1805. Curiously enough, throughout the world, producers of large disks of glass trace their success to information obtained more or less directly from Guinand.

Dr. Blair, whose success Mr. Scott, on the authority of the Rev. Dr. Dick, cites with approval,* contrived (*Edin. Trans.*, Vol. III., p. 53) a partly fluid achromatic object glass, with hydrochloric acid filling the space between the convex sur-

* *Trans.*, xxviii., 697.

faces of a meniscus and a plano-convex lens; but, as pointed out in the *Encyclopædia Britannica* (under *Telescope*, p. 143), such combinations are practically useless, not only from unavoidable leakage, but also because in fluid lenses changes of temperature set up currents equivalent in effect to want of homogeneity in the flint lens.

Kellner Lens in Erecting Telescopes.—In 1873 the Kellner achromatic compound lens eye-piece was, by means of two suitable additional lenses, first made applicable by Heller & Brightly to the erecting telescopes that American engineers commonly prefer. The result is excellent definition from the completeness of the achromatism, greatly increased light from the much enlarged opening of the diaphragm between the object lens of the eye-piece and the accumulative lens, and at the same time the spherical aberration is so completely overcome as to leave the field flat, and make stadia measurements very much more satisfactory.

Inverting Telescope.—In spite of the better magnifying power, better definition, better light and larger field of the inverting telescope for the same size and weight of telescope, and notwithstanding the remarkable ease of accustoming one's self to the inversion, American engineers generally demand that the telescope shall not invert. It seems to be a wholly unaccountable prejudice, considering the instrument's greatly increased lightness and convenience obtained with an inverting telescope of equal precision.

IV. Theodolite.

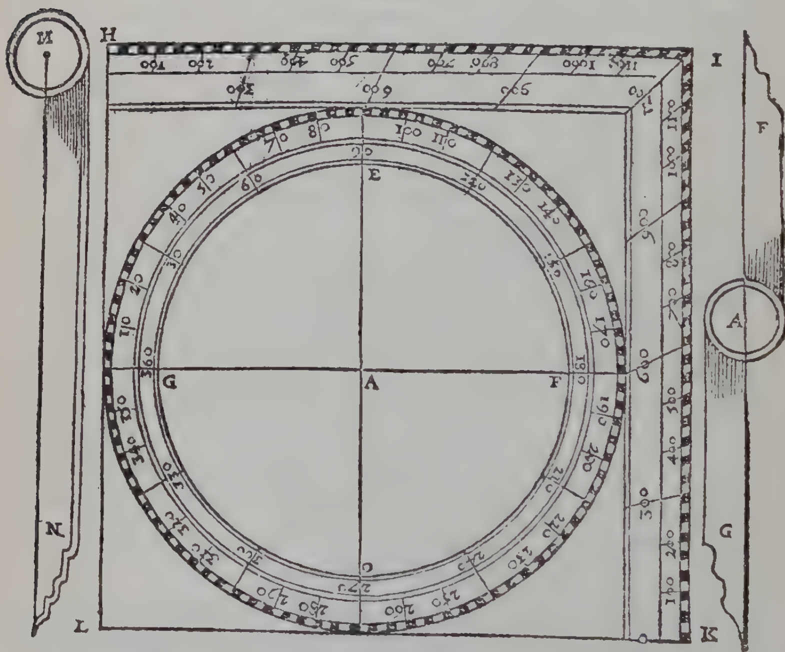
Origin.—The evident origin of the theodolite has been strangely overlooked by Mr. Scott, Mr. Hoskold and others in their examination of Digges's *Pantometria*. Obviously, not his *theodelitus*, but his "Topographicall instrument" is essentially the modern theodolite, with the yet unknown refracting telescope replaced by sights, and with the support for them and for the vertical semicircle reduced to a mere central pillar. His 29th chapter describes the instrument as follows:

"The Construction of an instrument Topographicall seruing most commodiously for all manner mensurations.

"Having alreadie plainly declared the making of the Quadrant Geometricall with his scale therein contayned, whose vse is chiefly for altitudes and profundities: the composition also of the square and planisphere or circle named *Theo-*

delitus for measuring lengthes breadthes and distances. Yt may seeme superfluous more to write of these matters, yet to finishe this treatise, I thinke it not amisse to shew how you may ioyne these three in one, whereby you shall frame an instrument of such perfection, that no mãner altitude, latitude, longitude, or profunditie can offer it selfe, howsoeuer it be situate, which you may not both readely and most exactly measure. You shall therefore first prepare some large foure square pullished plate of Latin, wherein you may describe your Geometrical square, his sides divided in 1200 parts at the left, with index and sightes as was before shewed : describing also within the same square the *Planisphere* or circle called *Theodelitus*, then must you vppon an other fine pullished plate, drawe your Quadrant, or rather a semicircle diuided iustly into 180 grades, and within the

FIG. 152.



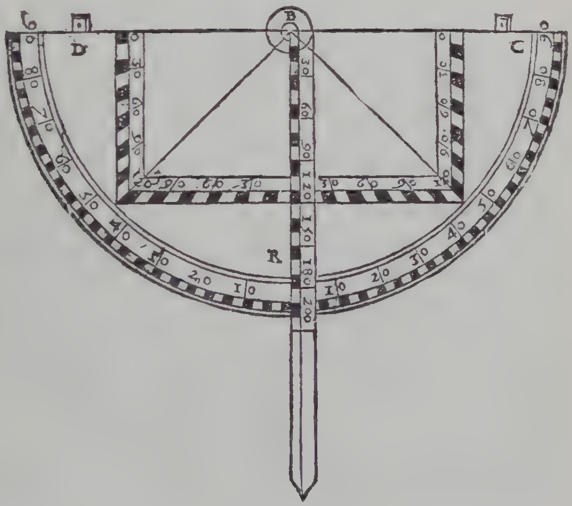
Digges's Square Geometricall, Index, Theodelitus and Alhidada.

same a double scale : every side contayning at the leste an 120 partes, finally, fixing on the dimetient thereof two sightes perpendicularly reared, and equedistantly persed, so as the line visuall may pass parallele to that diameter. You haue a double Quadrant Geometricall with a double scale, whiche you muste by the ayde of some skilfull Artificer, so place over the other plate wherein youre square Geometricall and *Theodelitus* was described, that his centre maye exactly reste in a Perpendicular line from the centre of the planisphere or circle named *Theodelitus*, his circũference depending dounwarde. And this double Quadrant or semicircle, must in such sorte be connexed to the Perpendiculare erected from the centre of the planisphere, and *alhidada* at the foote thereof, that what way so euer the Diameter with sightes be turned, the *Alhidada* maye alway remayne exactly underneath it, directing bothe to one verticall circle or pointe of the

Horizon : this perpendiculare wherevnto the semicircle's centre is fastened, ought also to be marked with 200 partes equall to the diuisions of the scale beginning at the centre, so proceeding dounward til you come to the end of those 200 portions : more I neede not say of this instrument, considering the construction, if every parte hath ben seuerally declared sufficiently before, for the placing and conioyning them, behold the Figures [Figs. 152 and 153].

"I K L H the square Geometricall, M N his index with sightes, G E F O *Theodelitus*, G F his *Alhidada* or index with sightes A B the line perpendiculare from B dounward noted with 200 partes, equall to the diuisions of the scale, D R C the semicircle hauing on his Diameter two sightes fixed as was to fore declared. This is also to be noted, that the double scale is compound of two Geometricall squares, the one seruing for altitudes, the other for profundities. The square which the line perpendicular cutteth when the Diameter is directed to any markes lying lower than your station, I call the scale of profundities, the other shall for

FIG. 153.



Digges's Semicircle.

distinction be named the scale of altitudes. This semicircle ought so to be placed that the centre B hang directly over the centre A, and that the diameter D C with his sightes may be moued vp and downe, and also sidewise whither you list, alwayes carying G F about directly under it. You must also prepare a staffe pyked at the ende, to pitche on the ground with a flat plate on the toppe to set this instrument vpon. It is also requisite that within *Theodelitus* you haue a needle or fly so rectified, that being brought to his due place the crosse diameters of the *Planisphere* may demonstrate the foure principall quarters of the Horizon, East, Weste, North and Southe: And this may you do by drawing a right line making an angle (with that one diameter of youre instrument representing the meridiane) equall to the variation of the cõpasse in your region : which in England is $11\frac{1}{4}$ grades or neere therabout, and may be redely observed in all places sundrie wayes. But thereof I mind not here to entreate, forasmuch as it appertayneth to *Cosmographie* & navigatiõ, whereof I haue cõpiled a treatise by itself, touching the fabricatiõ this may suffise."

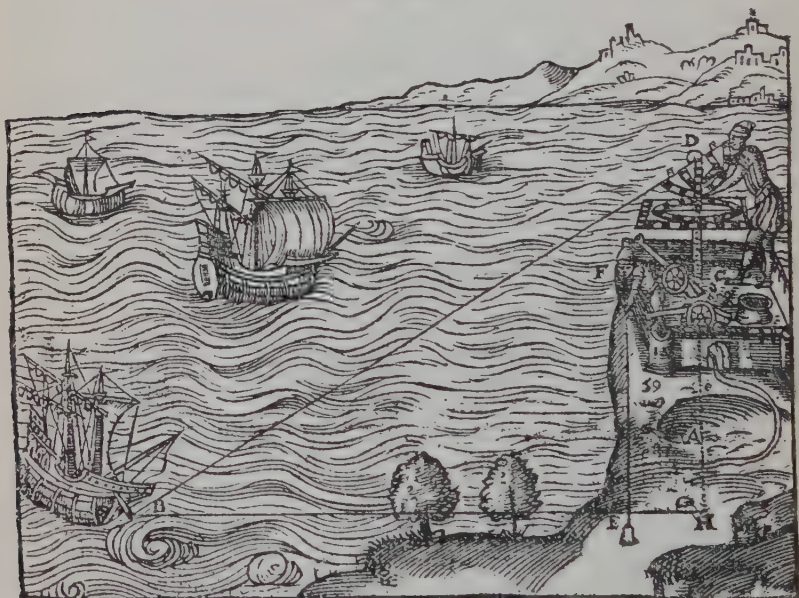
His 30th chapter begins:

"*By this instrument to knowe how many myles or pase any shippe is distante from you, your selfe standing vpon an highe cliffe or platforme by the sea coaste.*

"Your Topographicall instrument equedistantly situate to the Horizon, (as was before declared) turne the diameter of the semicircle towards the ship," etc.

It is perfectly clear from the figure (Fig. 154), as well as the text, that the instrument is nothing but the modern theodolite; except that it is rudely made, and that it has sights for the

Fig. 154.



Digges's Topographicall Instrument in Use.

naked eye in place of the refracting telescope not then invented. The vertical semicircle is joined to the sights just as it is in the modern theodolite to the telescope, but is supported by a pillar from the center of the horizontal plate, instead of by two standards or vees; and the pillar is joined to the alidade instead of to a vernier plate. To see the essential identity, it is only necessary to compare the figure with Figs. 16 and 17, pp. 696 and 698, vol. xxviii. of the *Transactions*. To be sure, the "square geometricall" has been disused in the modern form, and the graduated plate is round.

Digges expressly mentions the application of his instrument to underground use, meaning particularly military mines, at the end of the 35th chapter and of the "fyrst Booke," as follows:

"*A Note for Mines.*

"Most commodiously also serueth this instrument to conducte Mynes vnder the earth, for noting the Angles of position in the Planisphere or *Theodelitus*, and also Angles of Altitude or profunditie in the semicircle or scales appropriate therevnto, measuring the distances from Angle to Angle, you may make by the former preceptes most certeine plattes of your iorneis, and thereby always knowe vnder what place you are, and which way to directe your Myne to approche any other place you liste."

Derivation of the Name.—The derivation of the word theodolite has been variously explained, and generally quite ludicrously; for it has been a sore puzzle to philologists. Its first part has been imagined to come perhaps from Greek words meaning "to see a road" or to "run a road;" in either case requiring an *o* after the *d*, as in the ordinary modern spelling. But it is very noticeable that Digges, the first user, and apparently the inventor of the word, invariably spells it *theodelitus*, notwithstanding his extremely varied irregularity in the spelling of most other words. Now Mr. Scott brings to notice Stanley's and Bauernfeind's two other derivations, both as amusing as the old explanations, but not requiring either the *o* or the *e*, nor indeed hardly any of the other letters. It seems inconceivable that anybody could have formed the name of such an instrument from Stanley's *theodicaea*, divine right, aside from the lack of resemblance in form; or, according to Bauernfeind, have corrupted into *theodelitus* such familiar words as "the alidade," or, as Digges himself repeatedly calls it, "the Alhidada," one part of his instrument considered by him quite distinct from his *theodelitus*. Bauernfeind, in objecting to the derivation of the termination *lite* from *lithos*, stone, seems to overlook the fact that hundreds of mineralogical names are so formed in English; though, it is true, not so long as 300 years ago. But in any case, what in the world has the instrument to do with stones?

Perhaps the word was never quite correctly formed, but Digges's idea is probably indicated by his spelling,—at any rate not more absurdly than the previous derivations would appear. It looks as if his intention had been to combine the Greek

words θέα, or θεάομαι, viewing or observing, δῆλος, clear, or δηλόω, to make clear, and ἴτυς, the rim of a round body; meaning: a distinctly marked rim (or disk) for viewing, or for observation. If so, the second vowel should strictly have been *a*; but even the Greeks in like cases seem to have slipped into *o*, especially in later times; for example, Theogenes for Theagenes, and several compounds of σκιά, as in the English sciomachy and sciomancy. But possibly the first syllable is from θέω, to run or revolve; so as to mean a revolving, clear-making rim or disk. In use, however, the *theodelitus* was mainly stationary, while the alidade moved round. It may be objected that by the ordinary later methods of transliterating, the last vowel should be *y* instead of *u* (*theodelitys*); but until nearly or quite Cicero's time *u* would have been the letter to use, as in *cubus*, cube. It is said, too, that the learned Gladstone, of our days, so transliterated with *u*. It is nothing violent, then, to suppose that Digges did likewise; especially, seeing that he clung so closely to the Greek form as to give *Stratioticos*, instead of *Stratioticus*, for the title of one of his books.

V. Transit.

First Surveying Transit.—The first American transit for surveying was, according to Mr. Scott,* introduced by Wm. J. Young in 1831, following, however, probably after "Ramsden (1803), who introduced the transit principle in small English theodolites at that time." Also on page 697 Mr. Scott mentions "the transit-principle of Ramsden in 1803." It must, then, have been of the "*sic transit gloria mundi*" type; for Ramsden died Nov. 5, 1800. Mr. Scott refers to no authority; and was he not perhaps thinking of the portable transit indicated by Mr. Hoskold, Fig. 80,† as probably the one used in the surveys of the Box Tunnel, as mentioned by Bourns? Fig. 80 is copied from Simms's figure of an instrument made by Troughton; and is clearly not properly a surveying instrument at all, but merely a portable astronomical instrument, used in this case extraordinarily for a single sight or two in a tunnel survey. It seems clear, indeed, that the transit surveying-instrument was first invented and used in America.

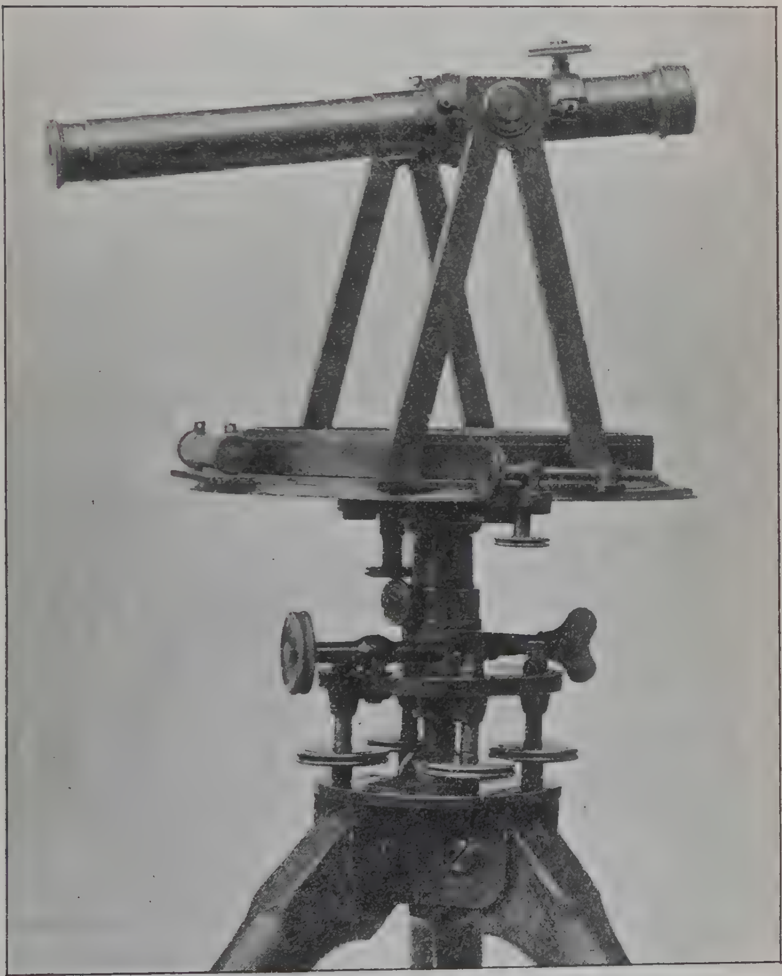
But who was really the American inventor of the transit?

* *Trans.*, xxviii., 703.

† *Trans.*, xxix., 975.

Mr. Scott gives no authority for his statement that it was Young in 1831. Others before Mr. Scott have made the same statement, and much color has been given it by Mr. Young's justly high reputation as an instrument maker; but did Mr. Young

Fig. 155.



Draper's Early Transit.

himself ever lay claim to the invention? There appears to be no evidence whatever that he did so.

Fig. 155 shows a transit by Edmund Draper, apparently of earlier date than 1831, and supposed by its owner, Mr. S. G.

Frey, of Watsontown, Pa., to date from 1821. But, as Draper died Dec. 24, 1882, "in the 77th year of his age," according to the advertisement of his death in the usually very accurate Philadelphia *Public Ledger*, he would have been only in his 16th year in 1821, and could hardly have invented and constructed a transit at that early age. Mr. Frey took the instrument to Mr. Draper in 1874, for repairs; and says that Mr. Draper, then an old man, after carefully looking it over, said: "Yes, I made that transit many years ago. It was among the first I put out when I commenced business, and it works as nicely now as it did when first made. But I cannot remember to whom it was sold, as I have not my old record at hand." It has latterly been announced that Draper begun business in 1815, but at that time he must have been no more than in his tenth year, and could have held only a very subordinate position in any business. Mr. Frey has had the transit ever since 1863, and the next preceding owner told him that he had had it since 1834. According to tradition, it was made by Draper in 1821, presumably to be used in surveying the Pennsylvania State canals and the Reading Railroad.

At all events, the instrument itself bears strong evidence of age, and has a decidedly more antique appearance than Young's; yet Draper was certainly never behind the times, and even in this early piece of work shows his superiority in the elegance of the proportions of the vees and other parts. One of the details, however, that give the more antique look is the greater height of the transit-plates above the tripod; for in the lapse of years, they have been gradually lowered towards the tripod, to secure more satisfactory steadiness. The telescope of the Draper transit is an erecting one of very weak power, compared with the inverting telescope of the Young transit, which appears, in fact, to belong to a much more advanced stage of optical development. Both instruments have the old arrangements for adjusting the telescope by shifting one end of the axle so as to make the cross-wires cut the same object that the sights of a compass cut when reading the same magnetic bearing from the same point. It was the early method for surveying transits, but was soon abandoned for the present much more accurate one of reversals, for adjusting the vertical cross-hair, or line of collimation—the method which had already

been used with the astronomical transit-telescope (though, in that case, with reversal of the telescope-axle in its wyes, end for end). On looking closely at the Draper instrument, small indentations may be seen in the lower parallel leveling-plate, which have been made by the leveling-screws; showing that the important device of placing a ring or disk of sole-leather beneath the screws, as a washer, upon the plate had not yet been adopted, as it may be perceived to have been in the Young transit. For the same purpose, flat-bottomed metal cups below the screws have been used, but are apt to get lost; and, as the bottom of the screws is not spherical, they are liable to bind at times. Heller & Brightly, in 1871, very satisfactorily gained the desired end by introducing a truly spherical cup and ball inseparably attached at the bottom of the screws. Draper's transit has straight spirit-levels, instead of the round one seen in Young's; for Draper never would use the round level, because it is sometimes impossible to seal it perfectly and permanently, and the difficulty of giving its interior a perfect curvature is greater.

Edmund Draper.—Draper, although he made no bluster and noise about his accomplishments, took great pride in his excellent skill and knowledge of his art, and is said to have earnestly declared that he would never have any "successor" in his business to diminish even indirectly his fair professional fame. Accordingly, after his death, in 1882, the business carried on from 1883 to 1892 with some of his old tools, but not even at the old stand, by Mr. Robert Wareham, who had been one of his workmen, was never made an excuse for assuming the title of Draper's successor. Later, after Mr. Wareham's death, a young man who had never worked with either Draper or Wareham, continued business at Wareham's place, with possibly some of Draper's apparatus; and now advertises himself as "Draper's successor." It must be done on the ground merely of being subsequent to him, without any idea that Draper or others would consider it an impropriety so to use his name, as an indication presumably of an authorized continuance of his skill and reputation.

VI. Instrument-Parts.

Ramsden's Dividing-Engine.—Mr. Scott says* "Jesse Ramsden had already (1760) constructed a circular dividing-en-

* *Trans.*, xxviii., 694.

gine," and is apparently corroborated by Mr. Hoskold.* In 1760 Ramsden was in the midst of the four† years' apprenticeship which he had begun in 1758,‡ after coming, at the age of twenty, to London in 1755. It was only in 1777 that he published a description of his celebrated dividing-engine, presumably just completed; and he was thereupon rewarded by the Board of Longitude.

Fineness of Graduation.—Mr. Hoskold is quite right in his conclusion§ that, as regards precision of the graduation, "there is a medium course," and that "it is necessary to determine the fineness of the divisions . . . according to the nature of the work and the degree of accuracy sought to be attained." But his illustration of the inaccuracy of coarser divisions is not very convincing. He arbitrarily supposes certain observed angles with a graduation to minutes, and shows the result of a whole minute of error in the sum of an angle and its supplementary angle. But a reading to the nearest minute (which is probable) and consistently with the two other suppositions would have shown no such error, and according to his reasoning would have proved complete accuracy; although the true angle might have differed by twenty seconds from the observation. Indeed, if his three supposed cases, with graduations to one minute, twenty seconds and fifteen seconds, were made consistent with each other and with the graduations, and the readings made to the nearest graduation, the result in each case would show complete accuracy in the sum of the angles, and consequently, according to him, complete accuracy in the observations, as follows:

Angle, ...	164° 32′ 0″	164° 31′ 40″	164° 31′ 45″
Supplementary angle, .	195° 28′ 0″	195° 28′ 20″	195° 28′ 15″
	360° 0′ 0″	360° 0′ 0″	360° 0′ 0″

The true angles may be near either of the pairs observed with the two more precise graduations, or may be between them. Clearly, the angle and its supplementary angle, if both were read correctly to the nearest graduation, will always sum up 360°; except that an error might occur when the truth is

* *Trans.*, xxix., 960.
† Grant, p. 490.
‡ *Dict. Nat. Biog.*
§ *Trans.*, xxix., 978.

exactly half-way between two graduations, so that a reading might be made in one case or the other that would cause an error to the extent of one graduation in the sum.

Conical Graduation.—Mr. Hoskold says* that graduations upon a conical or bevel-edge form are more easily read than those upon a flat surface. They are, indeed, slightly easier to read; because the eye is placed a little more conveniently in a line at right angles with the slope of the bevel-edge, instead of vertically over a horizontal plate. But the sloping graduations are disliked by instrument-makers, because more troublesome from the increased difficulty of correcting the centering and of getting the vernier precise; and therefore repairs are much more expensive.

Full Vertical Circle.—Mr. Hoskold says,† against Mr. Stanley's using a full vertical circle with only one vernier, that the only advantage of the full circle is thereby lost. But the full circle has the very important additional advantage that it enables the constructor to test the placing of the vernier so thoroughly as to make it trustworthy. A second vernier would give the same reading as the first, and would therefore be rarely used, if at all.

Leveling-Screws.—Mr. Hoskold says‡ that, "by preference, a triangular leveling and centering frame of light weight, with three leveling-screws, is attached to the theodolite;" and Mr. W. F. Stanley says§ that "the growing sentiment in England is greatly in favor of three leveling-screws." In America, four leveling-screws are constantly preferred to three, and apparently with good reason. Not only is the leveling effected more conveniently and speedily with four screws than with three, because both hands work at the same time, and consequently only one-half the time that one screw would require in bringing each level-bubble to its proper place; but also the construction of the tripod-head necessitated by the three screws is decidedly less satisfactory than when there are four. With four screws, the transit simply moves about a ball-and-socket joint in the tripod-head; but, with three screws, that arrangement is impossible, and the transit either rests by its own

* *Trans.*, xxix., 977.

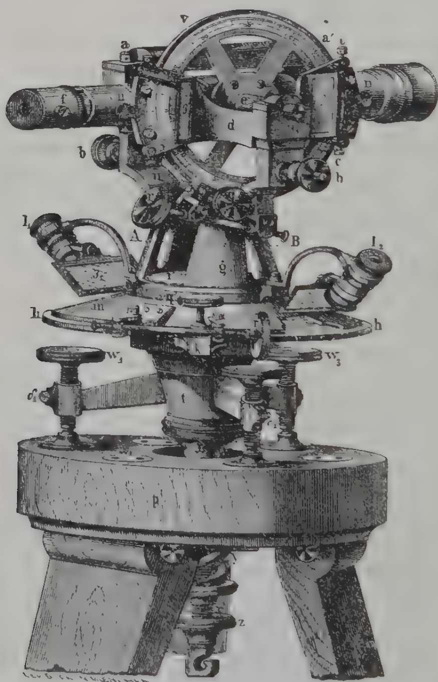
† *Remarks on Mine-Surveying Instruments, Trans.*, xxxi., 38.

‡ *Trans.*, xxix., 967.

§ *Trans.*, xxix., 940.

weight, without any binding attachment, upon a roughly horizontal plate at the top of the tripod, or, more usually and more securely, is united to the tripod by a central vertical shaft that is surrounded by a very strong spiral spring some five inches long, against which the leveling-screws pull. (See Figs. 156 and 157, copied from Bauernfeind, pp. 188 and 340.) The spring, after being in one position for some time, "takes a set," or relaxes slightly, and the transit ceases to be in perfect level,

Fig. 156.



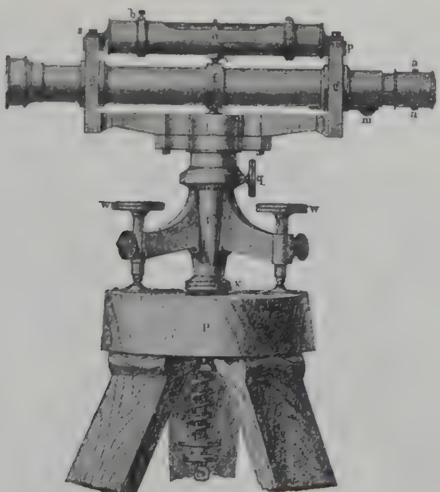
Three Leveling-Screw Method.

and needs to be leveled up anew. At each removal of the instrument from the tripod, the shaft must be unscrewed by a milled-head at its lower end from the socket of the instrument center above; and on replacing the instrument, must be screwed on again, and another milled-head nut must be turned to adjust the spring. For packing the instrument a specially arranged box is necessary that is less convenient than the arrangement that is possible with four leveling-screws, and cannot be made

safely to protect the instrument from injury, as it can with the four screws. Four leveling-screws, then, are decidedly preferable to three on the ground both of greater ease in operation, and of the still more important exigencies of accuracy in use and of safety and convenience in carrying.

In general the English tripod-heads with four leveling-screws give a very narrow base for the leveling-screws and for the top of the tripod legs, and are consequently unsteady compared with the American form. But the three leveling-screws requiring a wider base are more steady than the English four-

Fig. 157.



Three Leveling-Screw Method.

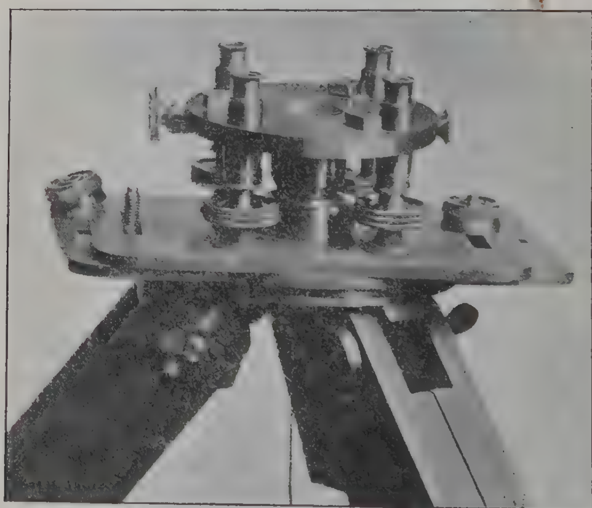
screw form, though too cumbersome to suit American engineers. That advantage of the three leveling-screws may explain the preference for them that Mr. Hoskold and Mr. Stanley say now exists in England.

Shifting Tripod-Heads.—Mr. Hoskold describes and illustrates* Troughton & Simms's shifting tripod-head, and says it is their invention. It is, however, essentially Edmund Draper's shifting tripod-head, with the addition of a clamping-plate to adapt it to use with three leveling-screws. Within a year after Young in 1858 patented the shifting tripod-head now claimed by Hul-

* *Remarks on Mine-Surveying Instruments, Trans.*, xxxi., 31.

bert as his own suggestion to Young, Draper, to attain the highly important object of the device and yet to avoid infringing upon Young's patent, very ingeniously contrived his own method, but did not have it patented. It is shown in Fig. 158. There are two horizontal brass plates, about 4 in. by 8 in., large enough to give great stability, the lower plate fixed upon the top of the tripod, and the upper or shifting-plate capable of moving in any direction upon the lower one, within a radius of about an inch, but restrained from wider movement by a small pin in a narrow slot near each end of each plate, the

FIG. 158.



Draper's Shifting Tripod-Head, with One Nut Removed.

slots of one plate at right angles to those of the other. The pins have a shoulder at the bottom and a screw-thread on their upper part, and the plates may be clamped together by a milled-head nut on each pin. The ball-socket is a part of the upper plate at its center. Upon the upper or shifting-plate rest the four leveling-screws. Draper's tripod-head has a larger movement than Young's, and in spite of its bulkier form is still preferred by some engineers, and is still manufactured. Its main objections are that the clamping-screws are liable to get lost in the field, and the large plates to get slightly bent and consequently useless.

About 1864, Mr. Chas. S. Heller (now of Heller & Brightly) contrived a shifting tripod-head, still in use, that is readily applicable to any old instrument, and precisely similar in principle to Mr. Hoskold's tripod-head of 1866.* A 4 in.-broad annular plate, or flat ring, of brass, with a wide hole in the middle for the shank of the instrument, and for the four leveling-screws, and with a screw-thread cut inside of a down-hanging flange at the rim, screws down upon the tripod-top, clamping the shifting-plate between it and the tripod-top. The four leveling-screws rest upon the shifting-plate. When the transit with the leveling-head is carried from one station to another, the clamping-plate hangs loose, making a little racket; and that small objection is the principal one against the arrangement.

Hoffman-Harden Tripod-Head.—Notwithstanding the ingenuity and the theoretically probable effectiveness of the Hoffman tripod-head, with or without the Harden improvement, apparently certain difficulties in practical use have caused dissatisfaction. The least dust upon the upper half-ball prevents smooth working; and a somewhat larger grain of grit there plows into the metal, and completely destroys the efficiency of the appliance. The upper half-ball unduly increases the height of the instrument. The number of joints between the tripod and the telescope makes the instrument comparatively unsteady. The approximate parallelism of the parallel plates of the tripod may be maintained without the device by merely careful setting of the tripod-legs, without or with extensible legs; as intimated by Mr. Hoskold.†

Heller & Brightly's Improvements.—In 1871, Messrs. Heller & Brightly introduced several important improvements in the construction of the transit. See the report on them by the remarkably able committee of the Franklin Institute. The weight of the transit was diminished about one-half by using cast bronze, cast under great hydrostatic pressure—with a "high gate"—instead of hammered sheet brass, and by ribbing and bracing the plates, with the removal of superfluous metal. An experience of almost thirty years has now amply proved the wisdom of the change of metal, though the excessively conservative

* *Remarks on Mine-Surveying Instruments, Trans.*, xxxi., 33.

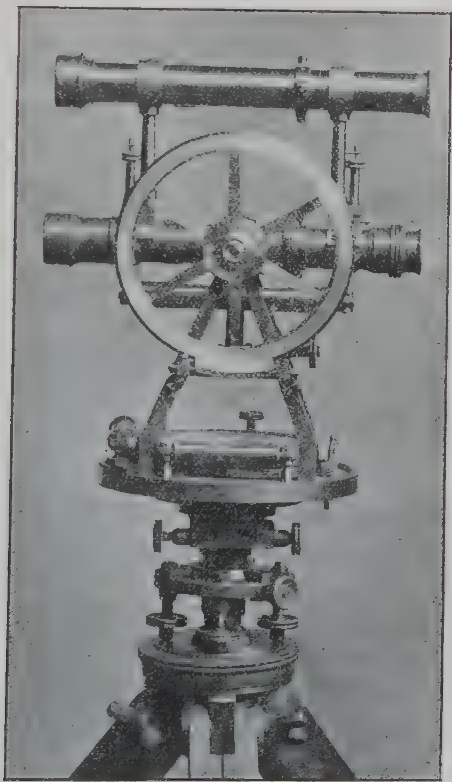
† *Ibid., Trans.*, xxxi., 30.

long maintained their doubts about so radical a departure from old practice. The method of attaching and detaching the instrument on the tripod was also improved by means of three lugs on the upper parallel plate of the tripod-head, all corresponding to recesses in a flange around the exterior of the socket enclosing the compound center, and one of the lugs being movable, so as to clamp the socket after turning the instrument until the lugs are away from the recesses in the flange. The tripod leveling-head was separately detached from the tripod. So detaching the transit proper, or level, with its long center from the tripod leveling-head, and this head separately from the tripod, enables the instrument to rest securely in its packing-box in precisely the same way as it does upon the tripod-head. Though more difficult, it is a securer plan than the ordinary one, and makes it possible to carry the instrument safely to distant countries. Owing to the great reduction in the weight and to the readier method of attaching and detaching the transit from the tripod-head, the compound center became feasible for ordinary use, instead of being virtually confined to the most accurate city- and tunnel-surveying. By degrees other makers have now adopted the same methods, so that the compound center has at length become common everywhere; and the "flat center" comparatively rare, with its friction between the plates, the quick wearing of the graduated plate around the shallow center, and the consequent inaccuracy of work, and with the exposure of the spindle, or turning-center of the entire instrument, whenever the transit is detached from the tripod-head.

Heller & Brightly also used a tangent-screw that overcame all lost motion, by means of a spiral spring that constantly presses the screw away from its supporting nut, not with the spring opening and closing to the extent of the whole motion of the screw, but merely to the extent of the backlash, by pressing against a detached follower within the nut. They extended the slits in the clamps on the axis of the telescope downwards almost to the bottom of the clamps, and made sighting-holes in the slits; so that an accurate sight at right angles to the telescope can be made. They made the tripod legs of semicircular cylinders sliding on one another's plane surface and clamping in any position; so as to give a play of from three to five feet

in length of legs. The tripod-head and the cheeks for the legs were made of one piece; so as to prevent the possibility of unsteadiness there; and the top of each leg enclosed a single cheek, instead of being enclosed by two cheeks. Pure plumbago was used as a lubricant for all the screws, preventing hard work in cold weather.

Fig. 159.



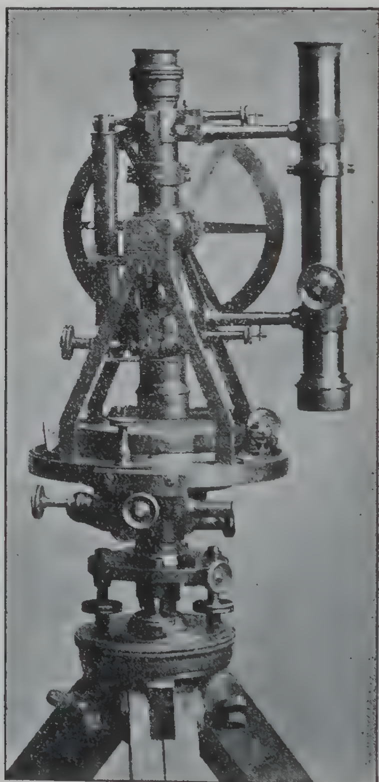
Heller & Brightly's Mining-Transit.

One small device of theirs is a great convenience in setting the transit precisely under a plumb-bob hanging from the top of a mine gangway. For that purpose, a small screw in the center of the top of the axle, or the binding-screw there that fixes the telescope in its axle, has a minute hole, say $\frac{1}{32}$ in., or less, in diameter, by a special apparatus drilled in the top exactly in the center of the axis of rotation of the transit. This form of the device dates back to about 1884; but from 1874,

the same object was effected by a small brass plate with adjusting-screws, and with the center marked by two lines crossing at right angles.

Heller & Brightly also constructed a mining-transit (Figs. 159 and 160), described by Dr. Raymond at our meeting of February, 1873 (*Trans.*, Vol. I., p. 375). It was a close copy

Fig. 160.



Heller & Brightly's Mining-Transit.

of their complete engineer's transit, but of reduced dimensions, making it the lightest American transit that had then been made. It had an erecting telescope $7\frac{1}{4}$ inches long; extreme diameter of plates, 5 inches; plate-graduation circle, $4\frac{1}{2}$ inches in diameter; a three-inch compass-needle; long compound centers; height of the instrument from the tripod legs, 7 inches; weight in all, about $5\frac{1}{2}$ pounds; besides a tripod of $3\frac{1}{2}$ pounds.

At that time, a prism and tube were provided to attach to the eye-piece of the telescope, for sighting vertically upward in shafts; but (as, notwithstanding Mr. Hoskold's argument* that sighting a telescope up a shaft gives the same angular result as sighting down it, the sight cannot be equally satisfactory if water be dripping abundantly upon the upturned object-glass) by 1876 a side-telescope was adjusted so as to be parallel to the central one, and was placed removably at the end of the main telescope axle opposite to the vertical arc. The effect of the eccentricity of the telescope can be corrected either by computation, or, more conveniently, by using a lop-sided or a double target. Mr. Hoskold† speaks of Combes and "the use of his double target." But it does not appear that Combes ever used a double target, or even a lop-sided single one. The double target given by Scott in Fig. 23A‡ appears to be of decidedly later date. Heller & Brightly later replaced the side telescope by an auxiliary top telescope, supported by two pillars, fore and aft, upon the main telescope; for the testing of the adjustment is far more convenient than with a side telescope, and a counterpoise, though quite feasible, yet so liable to be lost by a fallible mortal of a surveyor, is less necessary on account of the less serious effect of the weight of a top telescope, from its not tending to pull itself and the main telescope away from the correct vertical plane. The sights taken with the auxiliary telescope are, of course, comparatively very few, and at other times it is packed away with its pillars in the transit box, or in the surveyor's satchel, leaving the instrument wholly unincumbered and free from uneven wear of the center, even if there be no counterpoise. In using a top telescope, the correction of the observed angle for eccentricity from the center of revolution should not be neglected, especially in short sights; most conveniently by computation or by a small table. A small removable metallic reflector in the shape of a quadrant of a cylinder, to facilitate the reading of angles, was in 1873 applied just behind the vernier opening; also there was a small adjustable lamp-stand easily fastened upon one leg of the tripod, and quickly set so as to illuminate the cross-wires of the verniers. These last attachments are likewise useful in astronomical ob-

* *Remarks on Mine-Surveying Instruments*, *Trans.*, xxxi., 50.

† *Trans.*, xxix., 972.

‡ *Trans.*, xxviii., 706.

servations with the larger transit, in determining the true meridian.

Such, at that time, revolutionary improvements in transits well deserved the generous encomiums of Prof. J. B. Davis, of the University of Michigan, in describing Heller & Brightly's exhibits at the Centennial World's Fair. He says:

"I think their most valuable contribution to the advancement of their business is the spirit of invention and adaptation which they have awakened amongst their competitors. . . . One is surprised at every point, in examining the work of this Philadelphia firm, to see the extreme care and judgment with which every detail is worked out. One cannot well help referring the work of other makers to theirs as a kind of standard with which to compare it."

Indeed, it is quite incomprehensible how anybody in undertaking to write up "The Evolution of Mine-Surveying Instruments," with special allusions, moreover, to nearly every other surveying instrument directly or indirectly, even very remotely, connected with them, could have wholly failed to discover and mention an American establishment so prolific in important improvements in that line and so eminent in every branch of their business. The firm was established after the death of Wm. J. Young in July, 1870. The head and soul of the firm, Mr. Charles S. Heller, had been fifteen years with Mr. Young, the last five years of Mr. Young's life as his only partner. Mr. Brightly was one of their most skilful workmen. Mr. Brightly retired from the firm in 1889, and died in 1893.

VII. Other Instruments and Appliances.

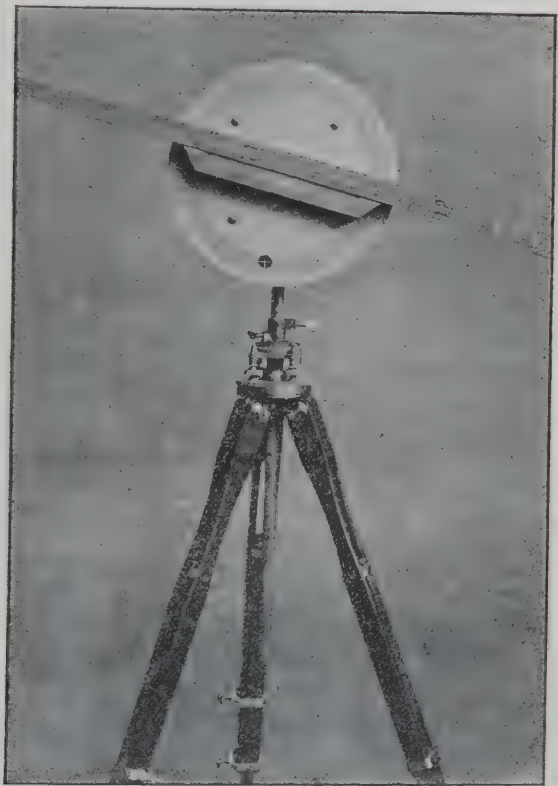
In a general account of "the evolution of mine-surveying instruments" several important improvements should not have been omitted that Mr. Scott seems to have overlooked.

Sunflower.—An instrument that has been found very convenient for measuring the cross-section of tunnels is called the Sunflower (Fig. 161). It was first made by Heller & Brightly from the design of Alfred Craven, a division engineer on the Croton Aqueduct, and was published in 1887.* It is a wooden disk about 15 inches in diameter, graduated to degrees, supported vertically by a tubular rod upon a tripod with extension-legs, and having across the center of the disk a wooden arm,

* *The Sanitary Engineer and Construction Record*, New York, June 11, 1887. See also *Trans. Am. Soc. C. E.*, xxiii., July, 1890, pp. 17-38.

metal-shod at the ends, that revolves on the plane of the disk, and bears a long graduated wooden rod sliding on the upper surface of the arm. There are two small levels for exactly plumbing the rod that supports the disk; and there is a sighting tube with cross-wires for testing the precise adjustment of the center of the disk to the center of the tunnel. One end of the

Fig. 161.



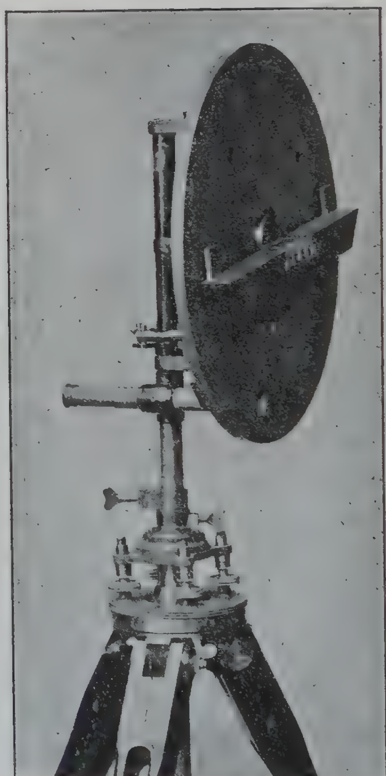
Heller & Brightly's Sunflower, Front View, with an Extension-Tripod.

wooden rod touches the perimeter of the tunnel, while the distance is read with a vernier at the center of the disk. The distances are taken at any desired number of angles around the whole disk, and are plotted conveniently with a protractor. (See Fig. 163.) The time required to measure a section of the tunnel is from six to ten minutes. The weight of the disk including all attachments is 10 pounds, and the tripod-head with

an extension-leg tripod weighs $10\frac{1}{4}$ pounds, making a total weight of $20\frac{1}{4}$ pounds. There are two measuring-rods, 8 and 14 feet long. The instrument is also useful for testing masonry work after the centers are struck.

Plummet-Lamp.—Eckley B. Coxe's plummet-lamp was described by Dr. Raymond, then President of our Institute, and

FIG. 162.



Heller & Brightly's Sunflower, Side View.

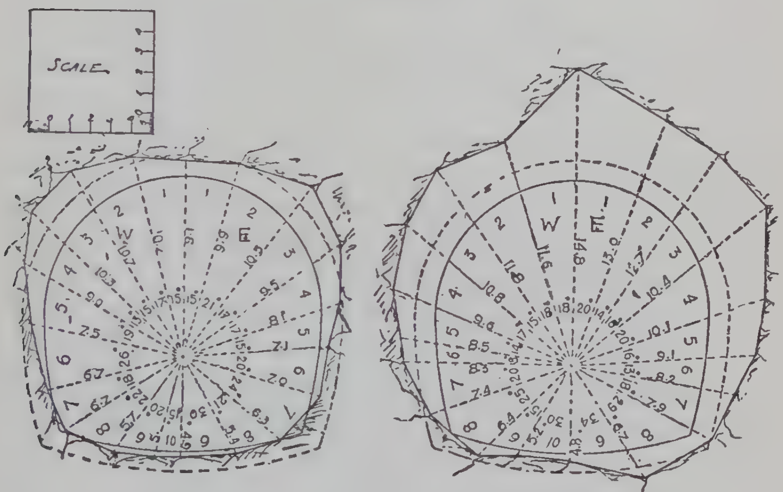
its use explained by Mr. Coxe himself in papers read before the meeting of February, 1873,* and was soon published in several journals. The lamp was made by Heller & Brightly, and was contrived for use in accurate mine-surveying to take the place of the open mine-lamp set (if not, as too often happened, overset) on the ground, or of the mere string of a plumb-bob

* *Trans.*, i., 378.

with or without a light or a white surface behind it. The plummet-lamp, as eventually made, rests by trunnions on a horizontal "compensating" ring, which at points 90° from the trunnions is hung by two light short chains from a cord that depends from a spud (a nail with a hole in the head) driven into the mine timber over a station, or into a wooden plug inserted in a hole drilled in the coal or rock roof. Mr. Coxe found that with the plummet-lamp "two persons can make a very accurate survey as quickly as three can by the old method."

Chains and Tapes.—Mr. Scott* says "the chain of Rittenhouse,

FIG. 163.



Tunnel Section-Measuring with the Sunflower.

house, which comprised 80 links or 66 feet, was quite generally used in American mines." Gunter's chain of 66 feet with 100 links is about 150 years older than Rittenhouse, and it would be interesting to know why 80 links should be used instead of 100. I have not discovered any reference to so singular an arrangement in any of the numerous works on Rittenhouse or by him.

Eckley B. Coxe was also the first to introduce, with Heller & Brightly's aid, the use of the long steel tape, or "chain-tape," at first 500 feet long, afterwards up to 1000 feet, instead of chaining. Formerly the graduation scratched on the tape, or

* *Trans.*, xxviii., 710.

marked with rivets, would often occasion breaking; or if etched on the tape, or marked on a thin layer of solder or tin, were not very legible or easy to find, and were easy to efface; the steel ribbon was soft, not tempered, and was consequently liable to alterations in length; and there was no reel. Heller & Brightly obviated all those difficulties. They soldered a small piece of brass wire with white solder across a tempered steel ribbon, with the solder for greater conspicuousness extending about an inch each side of the wire. The wire had a small notch at the exact end of the foot. They countersunk figures in the solder so that, no matter how dirty the tape, the figures are easily read, from being filled with dirt when the solder is wiped off with the finger. The tape is stronger at the graduations than anywhere else. Only every tenth foot is marked, and a five-foot rod is used for measuring the intermediate feet. The tape has a single wooden reel, with two detachable brass handles for use with the tape. Coxe gives in his paper the details of one out of three equally good surveys with the tape, showing, thanks to the tape, extraordinarily accurate work for that kind of mine surveying.

VIII. Scott's Tachymeter.

In regard to Mr. Scott's own instrument of 1896, which* "he ventures to assert, by its peculiar yet simple construction, embraces the advantages and eliminates the disadvantages of all other types," it may be unpardonable skepticism to doubt in the least degree its surpassing merits. Yet it does seem, after all, to fall in some points a little short of absolute perfection.

He says the auxiliary telescope has instead of cross-hairs a single one that is vertical when that telescope is on top and horizontal when at the side. Apparently, then, no point of observation can be fully fixed, with both horizontal and vertical angles, without taking two sights, with the telescope in both positions,—obviously a serious inconvenience. It does, moreover, seem to an obtuse skeptic that it would be more practical to have the supporting pillar of the auxiliary joined to it (in one piece, if you please—in that case, wholly giving up the

* *Trans.*, xxviii., 739.

unsatisfactory side use) and removable with the auxiliary, rather than to have the pillar always sticking up from the main telescope, and much exposed to injury, especially in a mine.

Furthermore, the lack of a compass seems to be a defect of some importance; but P. & R. Wittstock's detachable compass* in the place of the auxiliary above the main telescope, and incapable of use when the telescope is at all inclined, does not seem to be altogether practical, although Mr. Hoskold† has adopted a like situation for the compass, and distinctly recommends that method.‡ The U-shaped standards made possible by dispensing with the compass hardly seem by their grace or any other peculiar merit to make up for the loss of the compass. They are made of aluminum; notwithstanding the late firm of Buff & Berger, makers of this instrument, used to argue strongly and with much reason in their catalogue against the use of aluminum in surveying instruments, because its coefficient of expansion for temperature is so different from that of the other metals with which it must be replaced at the bearings and graduations, that the working results become very unsatisfactory as regards accuracy. But we are told§ the standards "will doubtless come into general use," and, of course, the instrument too. The inventor's charming zeal cannot but make us hope that our "old-time fancies" and doubts may indeed have to melt away before such success in actual practice, the true test.

IX. Nomenclature and Classification.

Names.—The names of surveying-instruments have varied differently from the instruments themselves, and have been used so diversely as to deserve a little elucidation and strict definition. In some cases a new name has been devised without any radically important change in the instrument; but more often the same name has been applied to somewhat radically different instruments, one form having been derived from another by repeated gradual improvements before a change of name was considered necessary.

For example, the name astrolabe, given, as appears from

---

* *Trans.*, xxix., 1009.

† *Trans.*, xxix., 965.

‡ *Remarks on Mine-Surv. Inst.*, *Trans.*, xxxi., 39.

§ *Trans.*, xxviii., 742.

Reinhold, in 1781, to a mere semicircle with two fixed sights and a movable alidade bearing sights, and 150 years earlier* applied to a copper disk for astronomical observations, hung vertically, with such an alidade, but with no fixed sights, was still used by Reinhold, after the addition of various improvements, for an instrument that is essentially a theodolite, with a vertical semicircle below a telescope, with verniers upon the horizontal alidade, with a compass and with an auxiliary side-telescope, Fig. 106. (*Trans.*, xxx., 799.) It seems clear that, instead of calling a theodolite an astrolabe, even though it be plainly developed from the astrolabe, the word astrolabe should at the present day be used only for the simpler forms, the forms to which it belonged before the invention of special names for the improved and essentially altered forms.

The name dial seems to have been derived from the graduation of a disk with the hours of the day; but has been applied, particularly in England, to a compass used in mine-surveying.

Circumferentor is a name that belongs strictly to a compass that is graduated continuously up to 360°.

The *Eisenscheibe*, or iron-disk, of Germany is a graduated brass disk turning horizontally and vertically in any plane by means of a ball-and-socket joint, and with two arms revolving upon the disk about its center, each hooked at the end to receive the measuring cords, and without a compass, and without either sights or a telescope.

The *graphomètre* of Gensanne (1770) appears from Schmidt's description† to have been merely an astrolabe of a simple form. But Komarzewski's *graphomètre* (1795) was an *Eisenscheibe* (iron-disk) with the addition of a vertical arc of 120°, the convexity upwards, upon the horizontal alidade.

The compass has as its principal feature the reference of all horizontal angles to the meridian by means of a magnetic needle and a graduated ring; and may have either sights or a telescope. If there be a special graduated plate for horizontal angles and a telescope and a vertical circle or arc, the instrument becomes either a theodolite or a transit, and the compass becomes a subordinate accessory. In the solar compass the meridian is taken from the position of the sun.

* *The Art of Navigation*, Martin Cortes, Seville, 1556. Cited in *Encyl. Britan.*, under *Navigation*. See Fig. 105, in Dr. Raymond's Discussion of Mr. D. D. Scott's paper, *Trans.*, xxx., 798.

† *Trans.*, xxix., 949.

The theodolite is capable of measuring both horizontal and vertical angles, with a graduated horizontal plate and a vertical semicircle below the telescope or the sight-bearing alidade. The telescope or sights can move a number of degrees vertically, but cannot revolve completely in the vertical plane. As we have seen, Digges's topographical instrument was essentially the modern theodolite in its most important distinctive principles. His *theodelitus*, however, was merely an astrolabe used for horizontal angles instead of only for vertical ones.

The transit likewise has the horizontal graduated plate; but the telescope is so mounted as to be capable of a complete revolution in the vertical plane. The telescope, to correspond with the astronomical transit-instrument or transit-circle, should be supported by a horizontal axis upon two standards and between them. But an instrument like Combes's of 1836, Figs. 109 and 110*, with its telescope supported only on one side like the telescope of the astronomical mural circle, or the sights of the older mural quadrant, has yet the more essential quality of the transit as distinguished from the theodolite, namely, the power to revolve the telescope completely in the vertical plane. Certain compasses, for example, the French square compass (*boussole carrée*), have such a side telescope; but have still been called simply compasses, because the compass was their principal feature and there was no special horizontal graduated plate. To apply the name mural, analogous to transit, would perhaps seem not wholly appropriate, because there is in a portable instrument no immovably fixed wall, as the very word mural implies. Perhaps the less compact term side-telescope-transit might be used.

The expression transit-theodolite is sometimes used, especially by men who have been more particularly accustomed to the theodolite. Their idea probably is that the distinguishing characteristic of the theodolite is the capacity of measuring both horizontal and vertical angles. But the expression is an inconvenient or clumsy one, and the difference between the transit and the theodolite is so radical and important as to justify the wholly distinct, simple name of transit.

Grouping.—The different instruments might perhaps be usefully classified in the manner of the following table, beginning generally with the simpler and older forms, and mentioning

* *Trans.*, xxx., 802.

some of the principal forms, particularly those that have had special names given to them. Instruments that combine the features of more complicated and simpler forms, as the theodolite and magnetic compass, or transit and solar compass, are well enough called by the more advanced name with the other name prefixed; as, compass-theodolite, solar-transit. The name Infallible is perhaps better suited for its class than Traverser; not only because it is older, but because traversing is done also with the theodolite and transit.

Classification of Surveying-Instruments.

A. Distance-measurers.
- Pole, cord, chain, steel-tape, odometer, pedometer, gradienter, stadia, barometer, etc.

B. Angle-measurers.
- I. Ungraduated Instruments.
    - Vertical angles.
        - Level.
    - Horizontal angles.
        - Plane-table, three-legged stool.
            - Without compass.
            - With compass.
        - Infallible.
            - Without compass: Douglas's Infallible, 1727. Zollmann's Scheibe, 1781. Henderson's Rapid Traverser, 1892.
            - With compass: Setz-compass, 1541. Agricola's compass, 1556.
- II. Graduated Instruments.
    - Quaquaversal:
        - Quadrant, sextant, octant.
    - Vertical angles:
        - Gradbogen. Sunflower. Clinometer.
    - Horizontal angles:
        - Without meridian:
            - Astrolabe. Digges's theodelitus, 1571. Gensanne's graphomètre, 1770. Eisenscheibe.
        - With meridian:
            - Compass:

Magnetic (including: Hang-compass, dial, circumferentor, 1796).
Solar.
Horizontal and vertical angles:
Without sights or telescope:
Komarzewski's graphomètre, 1795. Studer's Eisenscheibe, 1801.
With sights or telescope:
Theodolite:
Without compass (including Digges's Topographical Instrument, 1571. Junge's Goniometer).
With compass (magnetic, or solar, or both).
Transit:
Without compass (including Combes's).
With compass (magnetic, or solar, or both). (Including Morin's Combes's.)

Notes on Tripod-Heads, with Reference to Mr. Dunbar D. Scott's Paper on the Evolution of Mine-Surveying Instruments.

BY JOHN H. HARDEN, PHŒNIXVILLE, PA.

(Richmond Meeting, February, 1901.)

In the valuable paper of Mr. Dunbar D. Scott and its varied discussion, on the evolution of mine-surveying instruments, the tripod-head has not received the attention it merits. During the last 50 years this very necessary adjunct to the surveyor's instrument has been much improved. The legs are of better construction; and the devices for laterally moving the instrument over the station-point and for quick leveling, without the use of the screws, have given to the instrument fitted with the modern tripod-head the same facilities possessed by the old-fashioned ball-and-socket, with more perfect accuracy, not attainable in the latter, while saving from 30 to 50 per cent. of the time required for setting the instrument over a station.

For the purpose of extending the discussion to this import-

ant part of the instrument, the subject is here treated under the two divisions of the tripod-legs and the tripod-head.

Tripod-Legs.—Tripod-legs of wood have been made of different forms and cross-section, designed to suit surface or underground surveying of varied character, including:

1. The round leg, of equal diameter throughout its length, with metallic screw-joints in the middle, reducing the height of the instrument one-half, when required, as in the leg of the "Hedley" dial. This form of leg has no less than 9 joints, wood and metal coming together; it was never a firm, certainly not a durable support, owing to the contraction of the wood within the metal; and the attachment to the head gave an uneven movement to the joint.

2. The round leg, larger in diameter in the middle of its length, fitting between plates in the tripod-head. It is defective at this joint, and its movement is uneven.

3. The angular section leg (120°), in which three legs combined form, when closed, one compact round leg, sectionally larger in the middle of its length, very convenient and easy to handle. The joint with the head is metallic, insuring a uniform movement. The rigid fastening of the metal to the wood with wooden screws is not durable, owing to unequal expansion and contraction of the parts.

4. The lattice or built leg, solid for a short part of the lower length, spread to receive the joint at the head, and with one or all legs adjustable to the height of the mine or contour of the surface. This, the modern form of leg, is more nearly perfect, and gives a firmer support, without being heavier, than any other leg designed. All its parts adjust themselves and clamp together firmly, to make decidedly the best form of tripod-leg for all classes of instrumental work in the field or mine.

The Tripod-Head.—The tripod-head, connecting the instrument with the legs, was, in its earliest inception, a rigid piece of mechanism with ball-and-socket or screws (3 or 4) for leveling the instrument, after the legs had been manipulated to obtain the exact position, as near level as possible, over a station-point—an operation occupying much time and strategy, according to the nature of the ground.

In the year 1858 Mr. William J. Young, of Philadelphia, invented an improvement in tripod-heads, known as the "shift-

ing head." This was a decided improvement; for it enabled the surveyor to dispense, in a large degree, with the process of moving or depressing one or other of the legs to bring the instrument over the station-point exactly. This exactness is attained by moving the instrument laterally on the head, by means of the shifting-plate, within the limits designed—usually about one inch.

In 1877 Mr. Daniel Hoffman, of Philadelphia, introduced his improved tripod-head, with a quick-leveling device, together with the Young shifting-device. We now have a tripod-head with all facilities for adjusting the instrument over a station, approximately leveling it without using the screws, and requiring for the whole operation from 30 to 50 per cent. less time. The two devices mentioned, with the lattice-built legs, make a tripod fully equal to the other parts of a modern surveying-instrument.

Actual practice is the true test. I have used these devices on all my instruments during 20 years, and have proved them to be mechanically correct in principle, and to work well in practice. Never on any occasion has dust affected the smooth working of the upper half-ball, described by Mr. Lyman; and the tripods made by Heller & Brightly in 1879 are as perfect in their movement as they were the day they left the hands of the maker.

It is true that the height of the instrument is somewhat increased, though not to such an extent as to destroy its stability, firmness or usefulness.

It is also true that the approximate parallelism of the parallel plates of the tripod may be maintained, without such a device, by merely careful setting of the tripod, with or without extensible legs, as intimated by Mr. Hoskold. This careful setting of the tripod-legs, and the time required for doing it, is what is avoided in the use of the Hoffman and Young devices, which give to the modern tripod-head its superiority. In proof of this, the devices have had their imitators; the Young shifting-device having been imitated by Draper and others, and the Hoffman quick-leveling device by Young, Gurley and others.

In the suit of Hoffman *vs.* Young for infringement, decided by Judge Butler in favor of Hoffman, such eminent engineers as the late Eckley B. Coxe, Prof. Lewis M. Haupt, D. McN.

Stauffer, the late Thomas Shaw, and others, gave evidence in favor of the device as a valuable addition to the tripod-head, before unknown to them. The Hoffman invention, patented in England, has been largely applied to both new and old instruments by John Davis & Son, Derby.

In conclusion, I may refer to my paper, presented to the Institute in 1878, on "Imperfections in Surveying Instruments."*

Postscript.

Since the foregoing paper was written, I have received from John Davis & Son, Lim'd, Derby, England, a letter, dated February 8, 1901, and containing the following:

> "We continue to manufacture the Hoffman-Harden tripod-head ever since the patent expired—and the modified form for our small dials, which is appreciated.
>
> "We, however, find a tendency, particularly in South Africa, to favor the three-screw locking-plate arrangement, in preference to the Hoffman head with centering motion; and we think this system is likely to be more generally adopted throughout the mining world. We find that nearly all instrument-makers in this country have copied the Hoffman patent joint, some of them without the use of the name, adopting it as their own."

The D'Auria Air-Compressor.

BY HENRY G. MORRIS, PHILADELPHIA, PA.

(Richmond Meeting, February, 1901.)

The use of compressed air for the transmission of power has reached so great a development that we find numerous large establishments devoted to the manufacture of machinery for its production and application, and special periodicals published for the dissemination of information on the subject. Moreover, its employment is so general in mining operations that no apology is needed for the presentation to the Institute of such a paper as the present. The admirable articles of Mr. E. A. Rix, published in *Compressed Air*, show a wide range in the mechanical efficiency of air-compressors, varying, under different conditions, from 15 to 60 per cent.; and it is evident that any

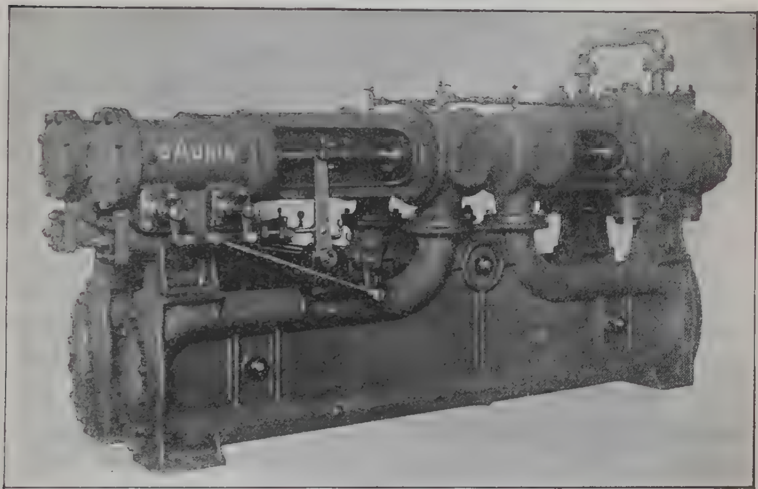
* *Trans.*, vii., 308.

improvements increasing the efficiency of these machines must interest mining engineers.

The present paper calls attention to a new form of air-compressor, so extraordinary in character that, had I not built several of them and seen them work satisfactorily, I would hardly dare to bring it forward as an accomplished mechanical fact: namely, the d'Auria air-compressor, built on the same principle as the d'Auria pumping-engine.

This is, as Fig. 1 shows, a non-rotative compressor of the duplex type. So far as steam-economy is concerned, it may be

FIG. 1.



The D'Auria Air-Compressor.

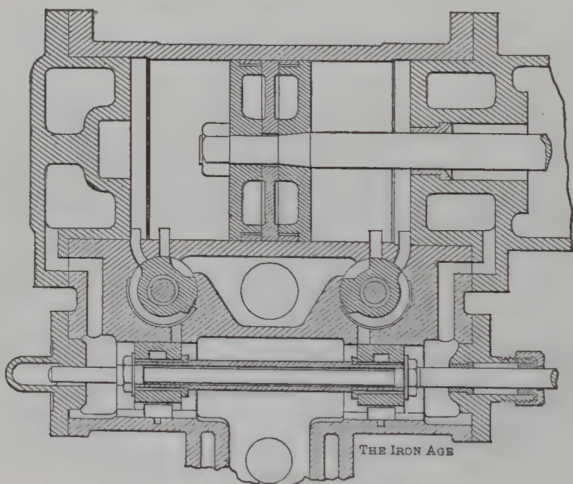
said to have less limitations than even a crank and fly-wheel compressor, for the simple reason that, while in the latter the high degree of steam-expansion calls for heavier fly-wheels, heavier crank-shafts, etc., the moving parts in the d'Auria compressor are not in the least affected by the degree of steam-expansion, and the machine works as well with a high as with a low expansion. Figs. 2 and 3 explain themselves.

Since there is no mechanism of levers, etc., employed to equalize the propelling force and the resistance at every point of the stroke (such as is used, for instance, in a Worthington high-duty pumping-engine), the question arises, how perfectly

smooth action is attained in the d'Auria compressor, starting at the beginning of the stroke with a high initial pressure of steam against no resistance, and ending the stroke with a propelling force practically *nil*, and resistance at a maximum.

This result is accomplished by the d'Auria "hydraulic compensator," which is a cylinder, fitted with a plunger carried by the same piston-rod which connects the steam- and the air-piston. The ends of the compensator-cylinder communicate with each other by means of a loop of pipe, turned into the form of a very rigid bed-plate, which adds to the strength of the machine, and preserves, under all conditions, the alignment

FIG. 2.



Section through Steam End.

of the piston-rod. This cylinder and pipe are filled with water or any other liquid; and, as there is no loss of liquid beyond that which may leak through the stuffing-boxes, are easily kept full from any source of water-supply, through the small pipe and two check-valves, shown in Fig. 3.

When the compressor is in action, the liquid column contained in the compensator-pipe is affected reciprocally, to and fro, by the plunger, and acts in exactly the same manner as a balance-wheel in a watch, taking up the excess of energy in the first half, and giving it back, with an exceedingly small loss due to friction, in the second half, of the stroke.

The action of this compensator is so perfect that the machine

is never bolted down to the floor on which it stands, and, under such conditions, can be run at a high rate of speed without vibrations. I have seen an 8 x 9 x 8-in. compressor of this type work suspended in the air from chains, and also run while on rollers, and another of the same size making 340 strokes per minute without being bolted to the floor—and under these conditions I was able to balance upon it a five-cent piece on edge.

These compressors have no dead centers. The cycle of their action being limited to the period of one stroke, they are able to start and stop instantly; and, if fitted with a sensitive pressure-regulator, they will stop completely on a small variation of air-pressure, and will start promptly when that pressure falls slightly below the normal.

It may be asked, What would be the effect of a sudden release of load on the compressor, such as might happen by the breaking of the air-pipe? This contingency is met in the d'Auria compressor, as in the d'Auria pumping-engine, by a simple and effective device. The exhaust-steam in the steam-cylinder is cut off by the piston itself about 1.5 in. from the cylinder-head; and from this point on a considerable amount of steam-cushioning is done in the cylinder, stopping the piston, under ordinary conditions, at about $\frac{3}{8}$-in. from the cylinder-head. Of course, this $\frac{3}{8}$-in. clearance is filled up with steam at boiler-pressure; which, while it does no harm, does a considerable amount of good by keeping the piston and cylinder-head hot when steam is admitted. On the other hand, the compensator-plunger has a number of slots, which, in case the stroke becomes longer than normal (that is, if the clearance becomes less than $\frac{3}{8}$ in.), overrun the bearing of the plunger and open a by-pass for the column of water which is pushing the plunger forward. Thus the pressure on both sides is equalized, and the pistons are prevented from striking the cylinder-head. Of course, this device comes into play only when the load is suddenly released. Under ordinary conditions, that is, with $\frac{3}{8}$-in. of clearance in the steam-cylinder, the by-pass in the compensator will not open.

The machine here illustrated is a small one. In larger sizes, the d'Auria compressors are made compound, both in air and steam, and fitted with the most approved steam- and air-valves

to insure economy of steam. A d'Auria compressor of 3000 cu. ft. capacity per minute, compound in steam and air, with inter-cooler all complete, weighs about 46,000 lbs., occupies a

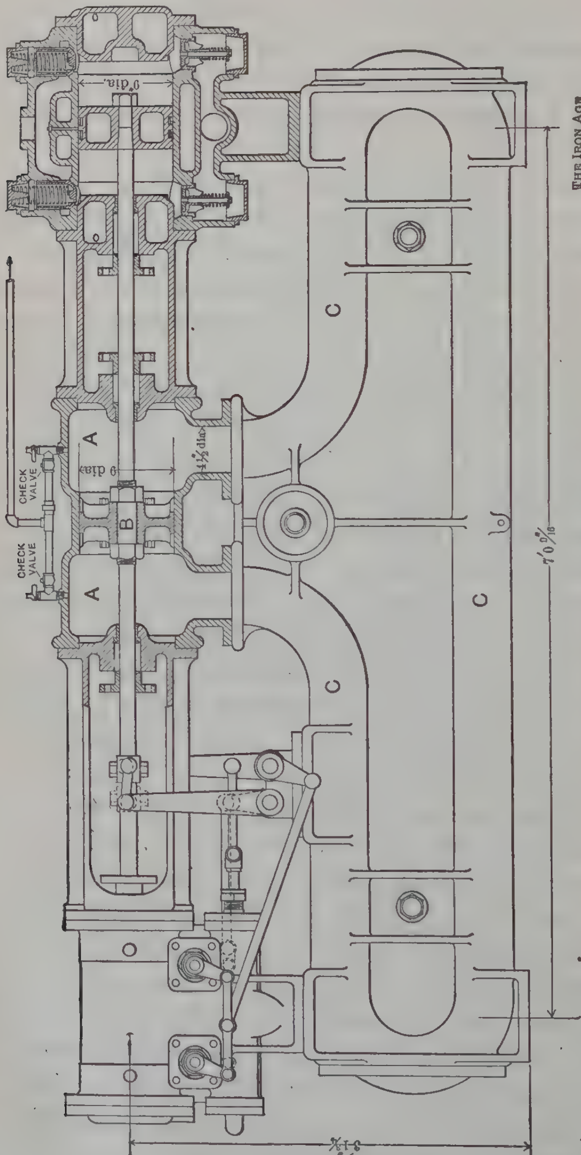


FIG. 3.

Longitudinal Sectional Elevation.

The D'Auria Air-Compressor.

floor space of 25 by 8 ft., requires no other foundation than a floor to support its weight, and does not need even to be bolted to the floor. A compressor of the crank and fly-wheel

type, capable of doing equally efficient work, and of the same capacity, would occupy a floor-space of about 56 by 18 ft., and its fly-wheel alone would weigh 45,000 lbs., the total weight of the machine being probably about 170,000 lbs.

Where space is a consideration, the new type offers considerable advantages, occupying only one-fifth as much area as the former type. In weight, it is as one to four, involving much saving in the cost of foundations, which is an important item. Moreover, it can be moved from place to place without any trouble, being, in the full sense of the word, a portable machine. No matter what its size, it will always start and stop promptly by opening or throttling the steam, without any dead center.

The principles involved in the d'Auria compensator have been recognized and stated by Prof. Goodman of Victoria University, Leeds, England, in his work on *Mechanics Applied to Engineering*; and the opinion of Mr. Charles A. Hague, a well-known American hydraulic engineer, is expressed concerning the pumping-engine (which involves the same principles) in the following extract from a letter addressed by him to me March 20, 1900:

"Several weeks ago I visited the Shawmont pumping-station, Philadelphia, and there saw one of the d'Auria pumping-engines at work against a heavy water-pressure, about 160 lbs. (400 ft.) per sq. in., and found that it was operating with great smoothness and regularity. I carefully examined its principles of design and construction, and it seems to me to be a most legitimate development and evolution of the Worthington duplex pump. Its principles of applying steam-power to the purpose of pumping water retain all of the simple details of the Worthington pump, and the methods and means provided for accomplishing the expansion of steam in a 'direct-acting' pump are marked by the entire absence of mechanism beyond the necessary cut-off valves, and one plain simple plunger, attached to each main piston-rod; the element of force necessary for the absorption and distribution of the initial and terminal steam-pressure being a plain, simple water-column, handled entirely without joints or working-pieces by the auxiliary plunger mentioned above.

"The indicator-cards seem to me to be practically perfect, and with the expansions shown, the economy of steam is assured, equal to any other type of pumping-engine producing the same diagrams.

"The peculiar features embodied in the relief of the auxiliary plungers at the stroke-ends, so as to make it possible to drive the engine boldly up to the finish of the stroke, and then stop the moving parts in a manner practically positive by the steam-cushions, is an admirable and effective feature, thereby providing for a uniform stroke without 'dash-relief' adjustments.

"The mechanical effect of the hydraulic balance, so to speak, is that of a swinging wheel, vibrating instead of revolving, but possessing important advantages over a rigid mass of metal; the water in the balancing column being more adapt-

able to the purpose at the critical instant of finishing the stroke, through the medium of the relief-openings in the auxiliary plungers.

"This engine is, in my opinion, a very reliable machine, and possesses the valuable feature of ease of handling, together with evident freedom from accident. It also seems to have in the most complete degree that sympathy with the main water-column so peculiar to the direct-acting pumping engine; the absence of which, in the crank and fly-wheel engine, demands the most careful attention in its design and operation, especially under heavy water-pressures."

Biographical Notice of James Wood Tyson.

BY WILLIAM GLENN, BALTIMORE, MD.

(Richmond Meeting, February, 1901.)

Early in the last century, Isaac Tyson, Jr., of Baltimore, was a miner of ores of chromium, iron and copper, and a manufacturer of their products. He was first to erect in America, for the reduction of copper-ore, a German blast-furnace, which was copied largely, and the improved successors of which are now universally used in this country. Dying in 1862, he left his manufacture of alkali bichromates to his eldest son, Jesse, while his work in the departments of mining and smelting descended to his second son, James Wood Tyson, the subject of this notice.

The father had mined chrome-ores in Maryland and Pennsylvania and manufactured their products at Baltimore; he had mined and reduced copper-ores in both these States; iron-ores at Tyson Furnace in SW. Vermont, and copper-ores in the northern and central parts of that State. Among his holdings was what later became the Ely mine, now called Copperfield. The son extended this work to central Georgia, and carried the family mining interests to the Pacific coast, where he took up chrome-mines in Oregon and elsewhere, as far south as southern California. On December 3, 1900, in the 73d year of his age, James Wood Tyson passed away, in his native city of Baltimore, charging his third son, James Wood Tyson, Jr., with the labors which, 38 years before, his father had resigned to him. Thus was the work of father and son in mining and metallurgy, continuing without interruption through almost

precisely three-quarters of the nineteenth century, left to the care of a son of the third generation. Yet so quietly was this work done, and so modestly had father and son conducted their lives, that few knew of them except as miners of chrome-ore and manufacturers of its products. They had lived as strict and consistent members of the Society of Friends, to which their forefathers had belonged—a Society which does not regard with favor any form of ostentation.

Justly and pre-eminently, the field of the Tysons has been that of chromium, an industry introduced by them into this country in the year 1827. A brief account of their work has been given by me in another place,* and need not here be repeated. I may, however, add to it, as a fact of historic value, and in some degree indicative of the reason of the continued success of the family business, that in 1846 they called to the aid of their bichromate factory at Baltimore the first chemist employed in technological enterprises on this continent. It was he whom all of us know as our brother in this Institute, Prof. W. P. Blake, so long a teacher at Yale, and still an industrious worker in the field of natural science.

After completing his studies at Haverford College, near Philadelphia, James Wood Tyson, at the age of eighteen years, began the mining and smelting of iron-ore at his father's works at Tyson Furnace, Vermont; nor was he afterwards to be idle for 55 years to come. His next labors were at Elba furnace, in the valley of the Patapsco, near Baltimore, where he produced pig-iron from ores mined at Springfield (the country home of the Patterson family, into which Jerome Bonaparte had married in 1803). But, contrary to anticipation, the Springfield mine ceased to afford iron-ore and did yield abundantly of copper-ore—a circumstance which led Mr. Tyson into the mining of copper-ores, and caused it thereafter to be perhaps the field which most delighted him. It may be said that of the six copper-mines in Maryland, five were either initiated or at one time worked by his father or himself; also, that the two Baltimore copper-smelting corporations, the Cuba Copper Co. and the Canton Copper Co. (the successor of which

* "Chrome in the Southern Appalachian Region," *Trans.*, xxv., 481.

latter is now the Baltimore Copper Smelting and Rolling Co.) were organized chiefly by one or both of them.

In 1831 Isaac Tyson, Jr., acquired one-half of a copper mine in the town of Strafford, Vt. The other half was acquired by James Wood Tyson in 1879, and in the year following he began work upon it. But it was not until after 21 years of patient development-work that he demonstrated it to be the most valuable copper mine the family had as yet owned. And, unfortunately, this result was not assured until shortly before his death, at a time when he was too much broken in health to regard with active interest or appreciation the success of his last labors. It is well to recall this instance in his mining career, because it so well illustrates the patience with which he carried forward his work, and also his unfailing devotion to an opinion which he believed to be well founded.

To his acquaintances, James Wood Tyson presented an unusually frank and pleasing presence; mild of manner, deferential, cordial and polite, but exhibiting reserve, as if by nature retiring. His inviting personality and manner assured to him acceptance in any society; and further acquaintance added to his social attractions. His intimates, who were few, knew in him all these admirable elements in an intensified form. He was a gentleman by instinct, holding strong religious beliefs, which dominated his acts; honest to the last degree; living freely an upright life.

Under his always gentle manner lay a character strong and positive. In action he was bold and fearless, as are those of his type always. Once determined upon a course of action, he sought his goal with all the forces he possessed, not being deterred or turned from his purpose by seeming failure or defeat, and never considering the abandonment of his object until it had been achieved, if his life should last so long.

To his large family and his near associates he was strongly attached, refusing to see their faults or their errors; always generous and good; considerate of them even if never considering himself. He was the closest and most genial friend with whom they were blessed.

Mr. Tyson joined the Institute in 1886, and attended several meetings thereafter, expressing great delight in the opportunity which they afforded to him, as a pioneer and veteran in Ameri-

can mining and metallurgy, to become acquainted with younger laborers in those fields. He promoted actively the Baltimore meeting of 1892, and cherished to the last a friendly interest in the work of the Institute.

Biographical Notice of Prof. Samson Jordan.

BY R. W. RAYMOND, NEW YORK CITY.

(Richmond Meeting, February, 1901.)

SAMSON JORDAN was born at Geneva, Switzerland, June 23, 1831. At the age of 20 years he entered the *École Centrale des Arts et Manufactures*, at Paris, from which he was graduated with high honors in 1854. After some months of service with the *Compagnie du Chemin de Fer du Nord*, he was employed (upon the recommendation of his former instructor, Prof. Burat, who had recognized his remarkable ability) at the mines of Portes, belonging to the *Société de l'Éclairage au Gaz et des Hauts Fourneaux*, etc., of Marseilles, and subsequently to construct the St. Louis iron blast-furnaces of that Co. After finishing this work, he remained at Marseilles as a member of the directory of the Co., particularly connected with the development of its mines. In 1862 he became the general advisory engineer of the Co., and still later (1873) its general manager (*Administrateur*), a position which he retained until his death, February 24, 1900.

He became subsequently *Administrateur* of other important French industrial enterprises, including those of the *Compagnie des Haut Fourneaux, Forges et Aciéries de Denain et Anzin*, and the *Compagnie Franco-Belge des Mines de Somorrostro;* and he was also, at various times, President of the *Société technique du Gaz*, Vice-President of the *Comité des Forges de France*, member of the Council of the *Société d'Encouragement pour l'Industrie nationale.* In all these positions, it is the unanimous testimony of his colleagues that he was no mere ornamental figurehead, but a profoundly wise, practical and industrious laborer and adviser, both patient and keen in the mastery of details, yet at the same time competent to apprehend the wider bear-

ings and the possible future of each undertaking to which he lent his skillful and experienced hand. I have grouped together the above incomplete data of his practical and administrative activities, and stated them at the beginning, in order to emphasize my opinion of the extraordinary degree in which M. Jordan combined the progressive and detailed knowledge of the practitioner with the theoretic insight and learning of the critic and instructor. Others have discharged, as he did, multifarious duties of administration and advice; others have made, as I shall show that he did, important contributions to technical literature and scientific progress; but I can scarcely recall any man of equal eminence in both departments whose theoretical views were controlled by so wide and accurate a knowledge of practice, while his practical activities were guided by so thorough an acquaintance with scientific theory and literature.

Before proceeding to consider M. Jordan's work in the latter (and more permanently important) department, I may here note that his merits in both departments were abundantly recognized by his election, in 1872, 1873 and 1878, as Vice-President, and, in 1874, as President, of the famous *Société des Ingenieurs Civils de France;* his appointment as Officer of Public Instruction; his decoration by his own government first (about 1868) with the cross of a Chevalier, and afterwards with the rosette of an Officer, of the *Légion d'honneur*, and by foreign governments with the orders of Commander of the Order of Isabella the Catholic, Chevalier of the Polar Star of Sweden and Norway, and Commander of the Order of Merit of St. Jacques of Portugal—honors which have little meaning to us Americans, unless they signify (as in this instance) the hearty appreciation of distinguished services rendered by their recipient to science, and therefore to mankind.

I now return to the consideration of M. Jordan's wider scientific activity.

In 1878 he was Vice-President of the International Jury at the Paris Exposition; at the Exposition of 1889, President of Committees and of the Jury of Class 48; and in 1900, Reporter of Class 64 of the Exposition of that year.

He published early a valuable treatise on the manufacture of

spiegeleisen, which he introduced at the St. Louis blast-furnaces in 1862.* From 1867 to 1897 he published, principally in the *Revue des Mines et de la Métallurgie*, or in the Proceedings of the Society of Civil Engineers of France, numerous memoirs of scientific and technical value. It is claimed for him that he was the first to make known (in 1869) the calorific theory of the Bessemer process. In 1870 and 1871 he contributed to the Society of Civil Engineers of France two important papers on the manufacture of guns and projectiles.

To these publications should be added the conspicuously able and comprehensive reviews of the science and practice of the manufacture of iron and steel, which he issued in connection with the various international expositions above mentioned.

During the period of more than ten years, from and after 1875, during which I was engaged in the conduct of litigation connected with the Martin open-hearth steel patents in this country, I had occasion to realize the extraordinary ability and learning of M. Jordan, who was my foreign associate and adviser, and who assisted me with opinions of wonderful acuteness, accuracy and fullness.

But this wide and ceaseless scientific activity served chiefly, after all, to enrich and enhance his life-work in the *École Centrale des Arts et Manufactures*, from which he had graduated in 1854, and to which he returned in 1863 as lecturer, becoming in 1865 full professor of metallurgy, a position which he occupied thenceforward until his death. It is seldom that students in such a school have the opportunity to listen to a professor who is also a man of affairs—at once a great theorist and a great practitioner.

Under this head, I cannot do better than translate (somewhat freely) from the oration pronounced at his funeral by M. Deharme, as the representative of the faculties of the *École Centrale*, and of thirty-five graduating classes of that institution, the following just and sincere tribute:

"Insisting no longer upon the merits of the metallurgist, which are universally recognized, I ask your permission only to state, in a few words, what Jordan was

* For an account of the development of this manufacture at these furnaces, and the steady increase up to 85 per cent. of the proportion of manganese in the product, see my paper on "Manganese Pig," *Trans.*, vi., 192.

in the *École Centrale.* To the qualities of an experienced engineer he added those of an instructor of the highest rank. His teaching was remarkable for clearness and accuracy, which conferred upon his illustrations and arguments, whether based on his ceaseless studies of French and foreign metallurgical processes or upon his own practical experience, an incomparable power.

"His interest in his pupils did not cease at the threshold of the school. Solicitous of their welfare and anxious for their success, he took pains to preserve for years, in a cipher to which he only possessed the key, his notes and opinions concerning their careers—setting down carefully each new circumstance that came to his knowledge, that he might make no mistake afterwards concerning its details or significance. It need not be said that this systematic and friendly remembrance earned for him the affection of all.

"In our councils, whether of instruction or of administration, the advice of Jordan was always dictated by a wise and firm prudence. The 37 years which, as lecturer and professor, he had consecrated to the school, had fortified his experience. He represented for us, as it were, our tradition; and his opinions possessed an exceptional authority, to which we delighted in giving homage. And at the end of a formal session he would lay aside the serious air, and become again in manner what in fact he had never ceased to be—the genial, sympathetic and affectionate friend."

My own personal acquaintance with Prof. Jordan began, I think, in 1873, when I revisited Europe, and, as President of the American Institute of Mining Engineers, attended the meeting of the Iron and Steel Institute at Liège. At that time he became a member of the Institute, the important work of which he continued thenceforward always to recognize and value. A little later, I became a member of the Society of Civil Engineers of France, of which he was President; and thus, through the proceedings of two societies, as well as the joint professional work I have already mentioned, I was kept "in touch" with him, though we did not meet again. I have not forgotten his manly and friendly presence; and I can heartily echo the sorrow and the praise expressed by his colleagues in many undertakings*—the record of which lies before me as I close this imperfect sketch.

---

* See *Proceedings of the Soc. of Civ. Eng. of France*, April, 1900, pp. 237–247, from which many of the particulars of this notice have been taken.

Problems in the Geology of Ore-Deposits.

BY PROF. J. H. L. VOGT, UNIVERSITY OF KRISTIANIA, NORWAY*.

(Richmond Meeting, February, 1901.)

TABLE OF CONTENTS.

Introduction.

In the latter part of November, 1900, I received through the Secretary of the Institute the papers of Messrs. Van Hise, Emmons, Lindgren and Weed, presented at the Washington meeting of February in that year, with the request (urged also by Mr. Emmons) that I would furnish for the Richmond meet-

* Translated by the Secretary, and translation approved by the Author.

ing a contribution to the discussion of the geology of ore-deposits, with reference to these four papers. It is a pleasure and an honor to comply with this request. I entertain a high appreciation of the progress of the natural sciences in America during the last half of the century. We Europeans realize that in many departments of these sciences America is taking the lead; and it is our desire that the Old and the New World may come closer and closer together in scientific union. This consideration has impelled me to the preparation of the present paper, for the deficiencies of which I must be permitted to offer an excuse in the fact that it was necessarily written within the period from December 3 to December 31. In many respects, therefore, it is incomplete, because time was wanting for a more thorough and comprehensive work.

I. The Original Source of the Heavy Metals of Ore-Deposits.

It is well known that many investigators, even in most recent years, have sought to derive the heavy metals of ore-deposits from the inaccessible interior of the earth. This hypothesis was favored by the remarkably high specific gravity (about 5.6) of the whole globe, which was explained by assuming that the heavier metals were concentrated in its interior. A further confirmation was sought in the quantity of iron found in meteorites, and also (by spectral analysis) in the sun. The earth's interior was regarded as a liquid molten mass, and the products of volcanic eruption as furnishing samples of this mass, bringing with them, from the richly metalliferous hearth of interior fusion to the upper horizons, or even to the surface, small quantities of metals and metallic compounds. In support of this hypothesis, the beautiful synthetic production, by sublimation, of cassiterite,* specular iron, etc., performed by Daubrée and other French experimenters in the middle of the nineteenth century, and received with universal and significant interest, has often been cited.

This hypothesis is seductively simple, but cannot be maintained. We must accept as now proved, that the interior of the earth cannot be regarded as a liquid molten mass. In the

---

* According to the equation, $SnCl_4 + 2H_2O = SnO_2 + 4HCl$.

words of the distinguished Swedish physicist, Svante Arrhenius,*

> "Modern investigations of astronomers and physicists show that the deformations of the earth's mass under the influence of moon and sun (tides of the earth's crust), and the variations of the earth's axis (called precession and mutation) due to the same outside causes, present such a quantitative order as to be irreconcilable with the assumption of a liquid interior."

He concludes that the crust of the earth is solid to the depth of about 40 kilometers. At the temperature of about 1200° C., and the pressure of about 10,840 atmospheres, existing at this depth, most of the ordinary minerals are fused, and dissolve the less fusible materials. That is to say, at the depth of about 40 kilom. begins a liquid molten condition, which, however, cannot continue to much greater depth. For at about 300 kilom. the temperature must without doubt exceed the critical temperature of all known substances; and at this point the liquid magma passes gradually to a gaseous magma, subject to extremely high pressure. The viscosity and lack of compressibility of this gaseous magma may be greater than those of the liquid magma.

We must give up, therefore, the old conceptions of the earth's interior condition. There is no reason for supposing that the heavy metals of ore-deposits have come from the enormously compressed earth-interior—which, as some physicists declare, must be, in consequence of such compression, "as hard as steel." In fact, no connection has ever been shown between ore-deposits and this heavy interior mass.

We are forced, then, to the conclusion that ore-deposits are derived from the crust of the earth—this crust, however, being regarded as not one or two, but 10, 25, or even 50 kilometers thick. Indeed, as will be shown below, a notable number of ore-deposits may be referred to eruptive processes connected, not with the heavy interior, but with the crust, of the earth. Many deposits, as Van Hise has recently shown, are due to the action of ground-water.

Moreover, it has been shown within recent decades that many elements, formerly regarded as very rare—often as totally absent—in rocks, are in fact almost invariably present in de-

* *Zur Physik des Vulkanismus* (*Geol. Fören. Förh.*), Stockholm, 1900.

tectable (though, of course, generally minute) quantity. On this point I may mention the investigations of the American chemists, F. W. Clarke and W. F. Hillebrand, and also my own paper on the relative distribution of the elements, etc.,* from which I here introduce a brief passage.

Distribution of Elementary Substances in the Earth's Crust.

Of the entire earth-crust,—namely, the rocks, sea and atmosphere,—oxygen constitutes by weight about one-half, and silicon about one-quarter; the proportions of aluminum, iron, calcium, magnesium, sodium and potassium range from 10 down to 1 per cent.; those of hydrogen, titanium, carbon and chlorine from 1 to 0.1 per cent.; those of some eight elements, phosphorus, manganese, sulphur, barium, fluorine, nitrogen, pretty certainly also zirconium and chlorine (but probably no others, with the possible exception of strontium), from 0.1 to 0.01 per cent. Between 0.01 and 0.001 per cent. come nickel, strontium (?), lithium, vanadium, bromine, and pretty certainly also beryllium and boron, but probably not tin, cerium and yttrium, or other elements. Between 0.001 and 0.0001 per cent. are cobalt, argon, iodine, rubidium, pretty certainly tin, cerium and yttrium, and possibly also arsenic and lanthanum, but probably no others. In summary, therefore, we have:

Terrestrial Distribution of Groups of Elements.

Percentage.	Number of Elements.
10 to 1,	6
1 " 0.1,	4
0.1 " 0.01,	8
0.01 " 0.001,	7
0.001 " 0.0001,	7

Similar figures are obtained for the intervals 50 to 5, 5 to 0.5, 0.5 to 0.05 per cent., etc., proving that there is a law of quantitative distribution of the 34 most widely occurring elements, according to which some 4 to 8 elements fall within each decimally-reduced interval. From this law we may with some confidence further infer that of the remaining, say, 37 known elements, some would fall within the next following

* "*Ueber die relative Verbreitung der Elemente, besonders der Schwermetalle.*" *Zeitsch. f. prakt. Geologie*, 1898, pp. 235, 314, 377, 413, and 1899, p. 10.

smaller intervals, for instance, between 0.0001 and 0.00001, or between the latter and 0.000001 per cent.

It may here be noted that all the more widely distributed elements (O, Si, Al, Fe, Ca, Mg, Na, K, H, Ti, C, Cl, P, etc.) have relatively small atomic weights. The 25 elements having the lowest atomic weights (up to and including iron) constitute at least 99.8 (more probably 99.85 to 99.9) per cent. of the earth's crust, while the remaining (say) 46 elements (among which barium, strontium, nickel, etc., are the most widely distributed) make up a total of 0.1, or at most 0.2 per cent. This is a result, on one hand, of the laws which controlled the formation of the elements themselves, which are probably to be conceived not as original and simple substances, but as compounds; on the other hand, of those which controlled the formation of the earth-crust from the original fire-mist of Kant and Laplace.

The elements of highest atomic weight are, then, on the whole, relatively the rarest in rocks; but that they do exist therein, though in minute proportions, and doubtless in some rocks as original constituents, may be shown, by way of illustration, for the platinum metals.

These metals are found here and there—often together with segregations of chromite—as primary segregations formed by magmatic concentration, in very basic eruptive rocks (peridotite, and, as reported in one locality, highly basic olivin-gabbro)—a fact which clearly indicates their original presence in minute proportion in these rocks. Moreover, in recent years a small proportion of platinum-metals has been found (as at Sudbury, Can., and Klefva, Sweden) in the segregated sulphide-ores of gabbro rocks—a fact which requires the supposition that the gabbro magma originally contained them. Some conception of this original tenor of platinum-metals may be formed from the statement that the nickeliferous pyrrhotites of Sudbury contain, according to many analyses, from 25,000 to 90,000 times as much nickel as platinum-metals; while the original proportion of nickel in the gabbro magma may be set down as about 0.05 per cent. Hence, on the (somewhat arbitrary) assumption that the platinum-metals were concentrated from the magma to the same extent as the nickel, the magma contained, roughly, 0.000001 per cent. of these metals. This figure, of course, has no pretension to accuracy; but we have at least learned that

even the platinum-metals are among the normal constituents of the basic eruptive rocks.

It can be similarly shown that minute quantities of gold and silver belong in eruptive magmas. For further discussion of this subject, and of the relative concentration of certain elements into the acid, and of others into the basic eruptives, I refer to my treatise cited above.

II. The Relation between Eruptive Processes and the Formation of Ore-Deposits, especially Such as have been Produced by Eruptive After-Actions.

In his latest paper, Prof. Van Hise divides ore-deposits into three groups, namely, those of direct igneous origin; those which are the direct result of sedimentation; and those which have been deposited by underground water. His first and fundamental premise is that the greater number of ore-deposits are the work of underground water. He asserts, further, that the material for ore-deposits is derived from rocks within the "zone of fracture"; that by far the greater part of the water depositing ores is meteoric; and that the flow of underground water is caused chiefly by gravity.

According to his view, by far the larger number of ore-deposits are formed by underground water, ore-deposits of direct igneous origin being "probably of limited extent," and the same being true of those which are the direct result of sedimentation (some placers, etc.); while possibly some are due to sublimation.*

In this paper I shall not discuss the sedimentary ore-deposits; but I may remark here that, in my opinion, there has been, of late, a frequent tendency to underestimate in this connection the importance of sedimentation as a formative agent.

From Prof. Van Hise's interesting paper, so rich in new theoretical suggestions, I have learned much; I believe that he has furnished the key to the genesis of numerous ore-deposits; yet at the same time, in my opinion, he ascribes to his theory too great a range, and, in particular, attaches too little importance to the direct genetic relation between ore-deposits

* "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 27, *passim.*

and eruptive processes. Many of the occurrences classed by him among the effects of underground water are, according to my view, the results of processes intimately connected with eruptive magmas, especially through eruptive after-actions (sublimation, pneumatolysis, pneumato-hydatogenesis, etc.) by which the heavy metals were in great part extracted from such magmas.

In order to make my view clear, I will here briefly mention a number of groups of ore-deposits :

Ore-Deposits Formed by Magmatic Segregation.

Ore-deposits formed by simple magmatic differentiation are confessedly infrequent, and therefore relatively subordinate in importance to other classes. Under this head may be named :* (1) The occurrences of titanic iron-ores in basic and intermediate eruptives, perhaps also of iron-ores in acid eruptives; (2) those of chromite in peridotites and their secondary serpentines (and also, according to J. H. Pratt, those of corundum in the peridotites of N. C.); (3) a number of deposits of sulphide-ores, particularly the nickeliferous pyrrhotites occurring in gabbro (at Sudbury, Can., Lancaster Gap, Pa., many places in Norway and Sweden, and Varallo, in Piedmont); (4) according to some authorities, the auriferous pyrites of Rossland, B. C.;† (5) according to B. Lotti, the high-grade copper-ores occurring in serpentinized peridotites in Tuscany and Liguria, Northern Italy (for instance, at Monte Catini), and analogous occurrences in other regions; (6) the occurrence of metallic nickel-iron (without economic value) in eruptive rocks; (7) those of the platinum-metals in highly basic eruptive rocks,‡ etc., etc.

It may be pretty safely assumed that the foregoing list will

---

* See my articles in the *Zeit. f. prakt. Geologie* during 1893, 1894, 1895 and 1900 (to be continued in 1901).

† Other authorities explain the Rossland occurrence differently. See "Biotitic Gold-Copper Veins," in Mr. Lindgren's paper (*Trans.*, xxx., 644).

‡ Already mentioned on page 129. It may be added here that, so far as known, all primary platinum deposits were formed by igneous fusion, and that the platinum-metals are either wholly wanting, or only exist in minute traces, in deposits from aqueous solution. The latter fact may be due to the small susceptibility of these metals, which are, for example, much less soluble in *aqua regia* than gold. (See *Zeitsch. f. prakt. Geologie*, 1898, p. 321.)

be enlarged by future investigations, though it can never become very extensive.*

Ore-Deposits Formed by Eruptive After-Actions.

But a different case is presented by deposits connected with the eruptives by pneumatolytic, pneumato-hydatogenetic, and other similar processes, the heavy metals of which, as I conceive, were mostly extracted from the eruptive magmas.

To explain this proposition, let us first remark that the eruptive magmas—at least those of deep origin—are admitted to be hydato-pyrogenic—*i.e.*, to contain a more or less notable admixture of water, with other constituents of hydrous or gaseous character. This is shown directly by observations of volcanoes, and indirectly, for example, by inference from the contact-metamorphism along deep rocks, which is conceived as a recrystallization under the influence of interpenetrating steam. Another indication is given by the enclosures of carbonic acid in quartz.

Concerning the chemical and physical action of water upon the magma, I quote the following passage from the work of Arrhenius, already cited:

> "The water in the magma . . . acts as an acid (strong as compared with silicic acid), liberating free silicic acid, H_2SiO_3, and free bases. By mixture with the unaltered magma, these become acid and basic silicates—the access of water having rendered the magma more liquid."

As is well known, the ionization of water increases rapidly with its temperature. This explains the activity of water at high temperatures. Thus, for example, Barus has shown that water heated above 185° C. attacks the silicates composing soft glass with astonishing rapidity; and an experiment by Lemberg has proved that water at 210° C. slowly dissolves anhydrous powdered silicates.

---

* Prof. R. Beck, in the first part (which has just appeared—Berlin, 1901) of his *Lehre von den Erzlagerstätten*, classes (with some doubt) the tin-ores of Etta Knob, in the Black Hills of Dakota, among magmatic segregations. This seems to me incorrect. The deposit mentioned, carrying cassiterite with apatite, triphyline, tantalite, columbite, spodumene, etc., presents, in its mineral paragenesis as well as in its geological occurrence, all the distinguishing marks of the tin-deposits formed by pneumatolytic processes—in this case intimately connected with the eruption of the granite-pegmatite. To this point I shall recur later.

Of special interest in the study of pneumatolytic phenomena is the following passage from the same work:

"So far as we know, all gases can be mixed with each other in any desired proportions. In the interior gaseous magma of the earth, therefore, there should be no permanent zones of segregation; but all occurring differentiations should lead to continuous transitions, and in the first rank of the forces operative in these would be osmotic pressures, of the detailed nature of which, at these high temperatures, little is yet known.

"In cooling, however, it is highly probable that this magma—at least, if it contained sufficient water—separates into two layers, after it has assumed a liquid state. The division takes place at a proportionately lower temperature, the smaller the amount of water. When this is very small, the products of the separation appear only as enclosures of water, carbonic acid, etc., at a very advanced stage of cooling, when the mobility is too small to permit the small drops to flow together and form larger masses. On the other hand, when the water-content is considerable, the aqueous gas collects in larger volumes, and in these are concentrated the bodies which, at the existing temperature, are more soluble in water than in the silicate-magma. Among these bodies are carbonic acid, hydrogen sulphide, combinations of univalent ions, such as those of chloric, fluoric and boric acid, with the mostly positive ions, like the alkali-metals, and, less frequently, the earthy metals, calcium, strontium and barium. The univalent ions have a strongly marked tendency to go to the water, because their compounds are dissociated electrolytically with extraordinary force. And among them the foremost must be those which possess a strong tendency to ionization, or, in the older chemical phrase, show strong affinity. Those ions, also, the hydrates of which are highly soluble in water without becoming dissociated, are favored in this process. This group includes, among others, the ions of carbonic and boric acid and hydrogen sulphide. Of course, silicic acid is likewise taken up by water in proportion to its solubility. (The ions of the bivalent metals—iron, zinc, lead, copper and tin—seem also to follow by preference the negative ions named.) In this solution, composed of bodies so various, the positive and negative ions are to be conceived, not as bound to each other in a definite way, but as mutually independent, as in an ordinary solution, such as sea-water.

"The cooling and the consequent separation into two layers occur soonest at the surface of contact between the eruptive and the cool adjacent rock; and it is natural to assume that later aqueous segregations will by preference accumulate with the earlier ones. Other portions are gradually collected as geodes and veins in the interior of the magmatic mass. By reason of the greatly superior mobility of the aqueous solutions, as compared with the magma, these segregations may send out branches in the form of the finest apophyses. The solution in aqueous gas now gradually cools, and one substance after another separates from it. By reason of the great mobility of the solution, and its consequent strong capability of diffusion, the minerals (provided the cooling be not too rapid) are segregated in large crystals, such as characterize a so-called pegmatitic structure. Gradually, also, the constituents which longest retain a gaseous form —such as water and carbonic acid—escape.

"According to this view, all the products required for the formation of 'pneumatolytic minerals' are simultaneously present in the aqueous solution; and it is not necessary to imagine that they come in gaseous form from different regions, to meet at the point of segregation."

After this theoretic explanation,* we may return to our consideration of the pneumatolytic or pneumato-hydatogenetic ore-deposits, beginning with those of tin-ore, the genesis of which has been especially studied by French investigators.†

Cassiterite-Veins and Apatite-Veins.—As is well known, the cassiterite-veins, of the type found in Cornwall, the *Erzgebirge*, Banca and Billiton, Tasmania, etc., are, everywhere in the world,‡ in connection with acid eruptives, namely, granite and (now and then) the veinstones and ejected rocks of the granite family, such as quartz-porphyry, liparite and rhyolite. Partly for this reason, and partly because of the characteristic paragenesis of the cassiterite-veins (presenting many fluoride-, borate- and phosphate-minerals), and the pneumatolytic metamorphism of the country-rock (forming *Greisen*), Elie de Beaumont and A. Daubrée, as is well known, concluded as early as 1840–1850 that these veins were connected with the granitic eruptions, and that in their formation various volatile fluorides, boron-compounds, etc., took part. Daubrée was led to a detailed theory by his famous synthetic experiments in sublimation.§

The genetic relations between the cassiterite-veins and the granite-eruptions may be followed a step further. It is first to be emphasized that the cassiterite-veins were formed immediately after the eruption—often, indeed, before the complete cooling—of the granite. One proof of this (among others) is the occurrence of the tin-vein-minerals in many veins of pegmatite with the granite.‖ It has been proved also by K. Dalmer in a thorough geological study of the deposits of the *Erzgebirge*. And it follows that, in this class of cases, ordinary underground water cannot have been active. We may assert, further, that the cassiterite-veins are genetically independent of the immediately adjacent country-rock.

---

* An attempt to explain the physics of magmatic differentiation under the influence of water dissolved in the magma will be found in an article which I shall publish in an early number of the *Zeitsch. f. prakt. Geologie* for 1901.

† The following statement is mostly a résumé of my treatise in the above-named journal (Nos. 4, 9, 11 and 12, of 1895).

‡ The peculiar silver-tin veins in Bolivia, described by A. W. Stelzner, are not here classed with tin-ore veins proper. Concerning contact-deposits of iron-ore carrying cassiterite, something will be said below.

§ See above, p. 126.

‖ See footnote, p. 132, above.

The geological features of these veins force us to the view that their material contents were extracted from the not yet fully congealed granite; and this view is confirmed by their mineralogical and chemical features. We find in these veins exactly the series of elements characteristic of the granite pegmatite-veins, such as potassium and lithium; also, tin, tungsten, uranium, niobium, etc., as well as beryllium (all also occurring with considerable frequency in the pegmatite-veins); and, finally, boron and fluorine.

Apatite-Veins.—At this point, I will briefly describe the Norwegian and North-Swedish apatite-veins. These veins are analogous to the cassiterite-veins, from which, however, they differ in many very instructive particulars.

The tin-veins are connected with granite; the apatite-veins with gabbro; and, in the latter case also, it can be shown that the veins were formed soon after the eruption of the rock, and that they cannot be explained by agencies acting upon the already congealed gabbro.

In both classes of veins we find a characteristic pneumatolytic metamorphism of the country-rock. Each class has in abundance a halogen-element: the tin-veins carrying fluorine (with a very little chlorine), and the apatite-veins chlorine (with a very little fluorine),* which occurs (1) in the mineral scapolite (containing about 2.5 per cent. Cl), abundantly represented in the metamorphosed zone along the vein-walls;† and (2) in the mineral chlorapatite.

In the tin-veins also, apatite or other phosphates are almost invariably found—sometimes, even, in considerable quantity.‡ This is specially noteworthy, because apatite is wholly (or almost wholly) lacking in lead-silver-ore veins, such as those of the *Erzgebirge*, the Harz, Kongsberg, Schemnitz, the Comstock Lode, etc., and in gold-veins generally.

Instead of the stannic acid, SnO_2, found in the tin-veins, we find in the apatite-veins titanic acid, TiO_2, as rutile (which is often so abundant as to be mined), ilmenite, titanite, etc.

---

* The Canadian apatite-veins carry a larger proportion of fluorine than the Norwegian.

† In the well-known apatite-deposit at Odegaarden, Norway, there is, on the whole, some 2.5 or 3 times as much chlorine as phosphoric acid.

‡ For example, the cassiterite-veins at Montebras in France are mined chiefly for the lithium phosphate, amblygonite.

The potassium- and lithium-minerals of the tin-veins are replaced in the apatite-veins by minerals of magnesium and calcium-sodium. The apatite-veins often contain some pyrites, and also, exceptionally, a little tourmaline—that is, a silicate containing boron.

While the characteristic elements of the tin-veins (Si, Sn, K, Li, Be; also W, Ur, Va, Ta, with F, B, P, etc.) remind us of the composition of the granite, we find in the characteristic elements of the apatite-veins (especially P, Ti, Fe, Mg, Ca, Na, Cl, etc.) a close analogy with the composition of the gabbro.

We conclude that the material of the apatite-veins was extracted from the gabbro magma in a manner similar to that of the extraction from the granite of the material of the tin-veins.

Since the halogens chlorine and fluorine respectively are so richly represented in these two classes of veins, we may conclude, further, that the magmatic extraction-process is based chiefly upon a reaction, in the pressure of water, of hydrochloric (or, as the case may be, hydrofluoric) acid, dissolved in the magma.

In my work of 1895, cited above, I have attempted to prove that by such an "acid extraction-process," operating in a granite magma, especially the elements K, Li, Be, Sn, W, Ur, Nb, etc., together with B and P, would be carried into the aqueous hydrofluoric solution; while, on the other hand, the aqueous hydrochloric solution in the gabbro magma would take up especially P, Ti, Fe, Mg, Ca, Na, etc. For this view I now find a support in the recent account by Arrhenius of the chemico-physical reactions of aqueous magmatic solutions.

Pegmatite-Veins.—A similar argument can be made concerning the "nephelin-syenitic pegmatite-veins of the southwest border-zone of the augite-syenite region," near Langesund-Brevig, in southern Norway, which have received so masterly an examination from W. C. Brögger.* We note specially that we encounter here a whole series of rare minerals, containing boric, zirconic, stannic and thoric acid (B_2O_3, ZrO_2, SnO_2, ThO_2), and also fluorine and chlorine; and that Brögger has established the following four phases of the vein-formation: (1) the phase of magmatic solidification; (2) the principal phase of pneuma-

* *Zeitsch. f. Kryst. u. Min.*, vol. xvi., 1890.

tolytic solidification; (3) the phase of the formation of zeolites; (4) the phase of the fluocarbonates, carbonates, etc. We note also that these veins are to be considered as contact phenomena.

Here we learn, on one hand, the action of the aqueous hydrochloric-hydrofluoric solution in the augite-syenite magma, and, on the other hand, the various stages of the vein-formation, in which the influence of (*a*) chlorides and fluorides, (*b*) water, (*c*) carbonic acid, etc., is operative.

From this brief digression outside the field of ore-deposits, strictly so called, we return to consider

Ore-Deposits of Contact-Metamorphic Origin.—These we may more briefly call "contact-deposits," in a limited sense of that term. As examples, we may take the iron-ore deposits of the Kristiania region, bordering the post-Silurian (pretty certainly Devonian) granites; also those of southern Hungary (at Vaskò or Moravitza, Dognaska, etc., in the Banat), bordering the late Mesozoic or Tertiary banatite eruptives; also those of the island of Elba, near Tertiary eruptives, particularly granite; and those of Dielette, in the department of Manche, France.*

The characteristics of this group of deposits are:

The ores (mainly magnetite and specular hematite, yet often also sulphides of copper, lead, zinc, etc.) occur within the metamorphosed contact-zone of deep eruptives, especially granite. Frequently they lie almost immediately at the boundary between the eruptive and the country-rock; frequently from 0.5 to 2 kilom. from that boundary, and sometimes even farther away (horizontally); but never outside of the metamorphosed zone. Not seldom they are found in fragments of metamorphosed slate or limestone, which have torn loose, and surrounded by the adjacent eruptive.

---

* I believe that numerous ore-deposits belong in this group of contact-deposits. But it is sufficient here to describe these from typical representatives, upon the following authorities: For the Kristiania region, the studies of Th. Kjerulf and my own earlier ones (with references in the *Zeitsch. f. prakt. Geologie* for 1894, pp. 177, 464, and 1895, p. 154); for the Banat (which I have also visited personally, with Prof. F. Beyschlag of Berlin), the work of B. v. Cotta (1864) and Edward Suess (*Antlitz der Erde*); for the Elba deposits, the investigations of B. Lotti; and for the French deposits, a description by Michel-Lévy.

More particularly, the ores occur in limestones, marly slates and ordinary clay-slates, and are accompanied by the usual contact-minerals, garnet, vesuvianite, scapolite, wollastonite, augite, hornblende, mica, etc.—and also (in the clay-slates) by chiastolite, etc. In other words, the phenomena of contact-metamorphosis are the same here as elsewhere, except that the minerals in the immediate vicinity of the ores are developed as very large individuals; *i.e.*, these ores have occasioned a contact-metamorphism of high potency.

Sometimes the ore-deposits are traversed by apophyses of the eruptive, such as veins of granite, quartz-porphyry, etc.

The Kristiania Deposits.—A study of the Kristiania contact-deposits indicates that the formation of the ores preceded the solidification of the granitic magma. Even when the ores occur in slates immediately adjacent to the granite, or in the small Silurian fragments completely surrounded by granite, they are never found also in the granite itself. This is to be simply explained by the supposition that from the still liquid magma the ores were "blown into"* the adjoining rigid rocks. If they had been introduced later, they would have been deposited in the granite also. In the Kristiania field, the contact-ores are found in pre-granitic rocks of all kinds—not only in limestones, pure and impure, and clay-slates, but also in Archean gneiss and pre-granitic porphyry-outflows. Hence this final deposition is independent of the chemical composition of the adjacent rocks. The presence in these deposits of granitic apophyses, already mentioned, is another proof that they were formed before the solidification of the granite.

We conclude, further, that the material of the ores was derived, not from the surrounding rocks, but from the eruptive magma. In the first place, their chemical composition (in the Kristiania region, as often elsewhere, showing a predominance, now of iron, now of copper, or, again, of zinc, lead, etc., associated with some bismuth, arsenic, antimony, etc.) is independent of that of the country-rock. In the second place, we often find the ores in rock-fragments, completely surrounded by granite,† so small that they could not have furnished the requisite amount of ore-material.

---

* I adopt this expression (*eingeblasen*) from my deceased teacher, Th. Kjerulf.

† Of 108 old mines and prospecting-pits in the Kristiania district, 16 per cent. are in small Silurian masses, completely enclosed in the granite; 20 per cent. im-

Contact-metamorphism is usually referred, in accordance with all probability, to the action of heated steam escaping from the eruptive magma and pressed into the surrounding rocks, where it produces a re-crystallization, in most cases without notable addition or subtraction of material. Contact ore-deposits form a special class of this metamorphism (involving "ferrization," etc.), and are explained by the presence of metallic compounds in the heated steam.

Other Contact-Deposits.—There is thus a close analogy between such contact ore-deposits as those of Kristiania, the Banat, Elba, etc., on one hand, and the tin-ore veins on the other—the latter being exclusively, and the former mainly, connected with granite eruptions. Indeed, there are also numerous intermediate transitional cases between these two. We may mention as instances the "tourmalinization" within zones of contact-metamorphism, well known in Saxony, and the similar "axinitization" of contact-metamorphic zones in the Pyrenees, which A. Lacroix has recently described. In these cases, that is to say, the boro-silicates, so well known in tin-veins, have been conveyed in great abundance into the metamorphosed zone. Fluorspar, tourmaline, axinite, etc., as well as the scapolite (which contains Na Cl), have also been found in our contact-deposits of iron-ore; while, on the other hand, specular iron is sometimes abundant in cassiterite-veins.

Moreover, there are metamorphic contact ore-deposits (characterized by garnet, augite, hornblende, etc.) which, besides magnetite, specular hematite, and sulphide-ores of copper, lead and zinc, carry also cassiterite, with its usual accompanying minerals. An instance is Pitkäranta in Finland, where, according to A. E. Törnebohm, the order of deposition was (1) iron-ore; (2) tin-ore; (3) copper-ore. Another instance is furnished by the "bed-impregnations" near granite, at Schwarzenberg in the *Erzgebirge*, recently described by K. Dalmer,* which carry as ore-minerals magnetite, specular iron, pyrites, galena, zinc-blende, etc., with cassiterite, wolframite, etc., further accompanied by pyroxene, actinolite, garnet, epidote, wollastonite, vesuvianite, etc., with fluorite, axinite and titanite. Under

---

mediately upon or near the contact between these rocks; 44 per cent. within the contact-zone, but farther away from the granite; and 20 per cent. in Archean rock and pre-granitic porphyry overflows, near the border of the granite.

* *Zeitsch. f. prakt. Geologie*, 1897, p. 265.

this head belongs perhaps also the peculiar occurrence of cassiterite and iron-ore in limestone near Campiglia in Tuscany,* 2.5 kilom. from a tourmaline-bearing granite.

Chemical History.—Chemically, however, the processes forming such contact-deposits of iron-ore, on one hand, and the cassiterite-veins on the other, must have been different. As already observed, the material of the latter was derived through magmatic extraction by an aqueous solution of hydrofluoric (and hydrochloric) acid; but in the ordinary, non-stanniferous contact-deposits of iron-ore the elements characteristic of the cassiterite-veins (Sn, W, U, Li, Be, B, etc.) are almost or wholly wanting, and, as a rule, fluorine is scantily represented. For these cases, therefore, an extraction by hydrofluoric and hydrochloric acid is apparently excluded. On the other hand, we may assume that the magmatic water itself has here played a specially energetic part, and has extracted iron from the magma. The detailed explanation is still an open question, in connection with which I may recall the theoretical proposition of Arrhenius, already quoted, that the water of the magma "acts, relatively to SiO_2, as a strong acid."

Pyritic Deposits.—As an appendix to the foregoing contact-deposits, I mention the pyritic deposits, typically represented at Vigsnäs, Röros, Sulitelma, etc., in Norway; Rio Tinto, Tharsis and San Domingo, in Spain and the adjacent part of Portugal; Agordo in Lombardy; Schmöllnitz in N. Hungary; etc. To these I would reckon also Rammelsberg in the Harz.

Concerning the genesis of these deposits, opinions notoriously differ. Some observers assert a sedimentary origin, while, in accordance with many others preceding me,† I ascribe the deposits to after-processes, following eruptive intrusions.‡

These deposits, which almost always have an apparently stratiform character, occur only either in rocks fully altered by dynamic metamorphism or in formations somewhat less powerfully compressed, and, generally, in close relation with erup-

* Described by B. Lotti and K. Dalmer, *Zeitsch. f. prakt. Geologie*, 1894, p. 400.

† Th. Kjerulf in Norway, K. A. Lossen in Germany, L. de Launay in France, Gonzalo y Tarin in Spain, etc.

‡ For my own works on this question, see *Zeitsch. f. prakt. Geologie*, 1894 (Röros and Rammelsberg) and 1899 (Huelva). I would mention also the studies of F. Klockmann, who defends the sedimentary hypothesis, *Id.* for 1895, p. 35, and *Sitzungsb. d. k. preuss. Akad. d. Wiss.*, Berlin, 1894, pp. 1173–1181.

tives. This last feature is highly characteristic of the numerous Norwegian deposits scattered between 59° 20′ and 70° of N. lat., along the old mountain-range which consists of Cambro-Silurian slates, probably folded in the middle Paleozoic (Devonian) age. Their distribution is such, however, that they appear only in those parts of the range where considerable outbreaks of eruptive rocks (gabbro, often accompanied by a granite rich in soda) took place, at about the period of the mountain-folding.

Of 28 Norwegian pyrites-deposits, enumerated in my treatise of 1894, 26 were proved to lie very near, or actually within, regions of compressed gabbro. I can now add that in one of the two cases then excepted we have found the eruptive rock near the mine. Since the deposits, moreover, are independent of the age of the slates (mostly phyllite- and mica-slates), their genetic relation to the eruptives is indisputable.

Some of them occur on shearing-planes in the compressed gabbro; but the great majority are in the slates surrounding it, most frequently at a distance of from 50 to 500 meters from the eruptive border, and rarely somewhat farther away.

We may note, further, that the pyritic deposits themselves (as has been shown by A. W. Stelzner and others) have sometimes been compressed—*i.e.*, they were completely formed before the end of the folding of the mountain-chain. Moreover, in many places they are traversed by apophyses of the eruptives, *i.e.*, they were formed before the solidification of the deeper portions of the eruptive magma.

It follows from these considerations that the Norwegian pyritic deposits are to be classed as phenomena of contact-metamorphism connected with the gabbro and its peculiar accompanying granite, and that their bed-like appearance must be explained by the occurrence of the gabbro eruption during the long period of mountain-folding. The ores were thus formed under extremely high pressure, which favored their introduction up and along existing planes of stratification.

The analogy of these cases with those of the ordinary contact-deposits already described covers also the origin of the ore-material, which we must assume to have been somehow extracted from the eruptive magma. This view is supported by (1) their independence of the adjacent slates; (2) their

formation immediately after the gabbro eruption; and (3) the resemblance of their material to that of the nickel-pyrrhotite deposits, considered to be products of magmatic secretion. The chemico-mineralogical difference between the two classes is, that in the magmatically secreted pyrrhotite deposits nickel predominates over copper, while in the pyritic deposits the contrary is the case. Yet in chemical respects there exist complete intermediate transitional occurrences, which I hope to describe at some future day.

The detailed explanation of the magmatic extraction forming the pyritic deposits is an entirely open question; but we may conceive it to be the combined action of water with a sulphur-compound.

What I have said of the Norwegian pyritic deposits holds good, I believe, in its main features, though with modifications of detail, for the other deposits of this class, mentioned above.

Veins of Gold, Silver and Lead-Ore.—These may be divided into three main groups: (1) relatively recent gold and silver, or silver-lead veins; (2) old silver-lead veins; (3) old gold-veins.

Gold- and Silver- or Silver-Lead-Veins of Later Age.—As representatives of this class we may name those of Nagyág-Verespatak in Transylvania; Schemnitz-Kremnitz and Nagybanya-Kapnik in upper Hungary (all of which lie along the Karpathian range); Cripple Creek, and many other Colorado occurrences in the Boulder, San Juan, Silver Cliff, Rosita and other districts; the Horn Silver and many mines in Beaver county, Utah; the Comstock, Esmeralda, etc., in Nevada; and San Bernardino in California; the districts of Durango, Fresnillo, Zacatecas, Guanajuato, Pachuca, etc., in Mexico; Cerro de Pasco in Peru; Potosi, Huachuca, Oruro, etc., in Bolivia, and many others along the South American Andes; the Coromandel peninsula (Hauraki) in New Zealand; and, finally, many places in Japan. This list, though far from complete, may serve to give a notion of the wide distribution and the economic value of the deposits of this group.

Its general features were first described by F. v. Richthofen, forty years ago. We may also refer here to the work of E.

Suess,* and to numerous treatises which have appeared in recent decades.

The younger gold- and silver-veins stand closely related to recent (especially Tertiary, but sometimes late Mesozoic, and occasionally to Quaternary) eruptive rocks.† But they are not confined to any one of the recent eruptives. Many occur in andesites; others in dacites; others, again, in quartz-trachytes, rhyolites, etc., and some in phonolites; so that they are to be considered rather as products of general volcanic activity. In fact, they belong, as a rule, in each district to the latest, or one of the latest, epochs of volcanic activity for that district. Hot springs, solfataras, etc., are frequently found near them.

Very often they carry silver and gold in combination (Comstock, Schemnitz, Nagybanya-Kapnik, etc.), the gold being sometimes predominant, with little silver (Cripple Creek, Transylvania), and sometimes *vice versa* (at many places in Mexico, Bolivia, etc.). Galena is in some cases abundant, but often almost or wholly absent (Transylvania, Cripple Creek, Comstock). Ores of copper and zinc are, as a rule, scanty; arsenic and antimony pretty common; and the frequent abundance of arsenical and antimonial sulphides is noteworthy.

A special sub-group is formed by the tin-bearing silver-lead-bismuth-ore veins of Bolivia, examined some years ago by A. W. Stelzner,‡ which carry cassiterite, and occasionally also the sulphide, stannite, while the accompanying minerals usual in cassiterite-veins are wanting. Cassiterite has been found also in some recent ore-veins in Mexico (and wolframite at Kapnik, Hungary).

Tellurium occurs abundantly in some gold-veins (Nagyag; Cripple Creek and other places in North America—especially in Colorado; Hauraki, N. Z.),§ but is lacking, wholly or nearly, in most cases. Selenium occurs occasionally.

The gangue-minerals are chiefly quartz and carbonate-spars, sometimes heavy spar (barite). Fluorite is usually absent, but

---

* *Zukunft des Goldes*, 1877.

† What follows is a summary of my views as expressed in the *Zeitsch. f. prakt. Geologie*, 1898, pp. 416–420, and 1899, pp. 10–12.

‡ *Zeitsch. d. d. geol. Gesellsch.*, Bd. xlix., 51 (1897). Published after Stelzner's death by Bergeat.

§ The large tellurium-gold-veins at Kalgoorlie, W. Aust., probably belong, not to this younger group, but to the older one above mentioned.

occurs here and there in abundance, *e.g.*, in the celebrated tellurium-gold field of Cripple Creek, Col.,* and in the Judith mountains, Montana.

Of the characteristic alteration of the country-rock along the veins to propylite, with sericite, kaolin, carbonate-spars, etc., Mr. Lindgren's recent paper in these *Transactions* gives a general account. I shall say more concerning it in the next part of this paper.

The Older Lead-Silver Veins, and the Older Gold-Veins.—The lead-silver deposits of Freiberg, Annaberg and Schneeberg in the *Erzgebirge;* Clausthal and Andreasberg in the Harz; Kongsberg in Norway; Przibram in Bohemia, etc., and also the old gold-quartz veins of the Mother lode in Cal., Berezowsk in the Urals, etc., show in numerous instances an undeniable dependence upon eruptive processes and mountain-foldings. But here also it is impossible to establish a universal relation between a given kind of vein and any particular eruptive rock. The silver-ore veins, for instance, occur in connection now with basic, now with acid eruptions.

Between these older and the younger veins there are several well-known differences. The presence of both gold and silver, in considerable proportions of each, displayed by many of the more recent veins, has never been observed, so far as I know, in the older ones.

Again, the older veins do not exhibit the propylitization of the country-rock, so characteristic of the later ones; but there is, instead, in many cases, as described by Lindgren, a somewhat similar alteration (carbonatization or sericitization). Moreover, the quantity of sulphides or, generally, of compounds of arsenic, antimony and bismuth (and, in Bolivia, of tin) is, on the whole, not so large in the older as in the later veins.

Yet, notwithstanding these and other differences, we must, in studying the question of genesis, emphasize rather the analogies between the two classes. There is, for instance, a significant similarity in many respects between the late lead-silver-

---

* Some American observers have assumed a genetic relation between fluor-spar and tellurium (or the telluride gold-ores). This I cannot accept, in view of the absence of fluor-spar from other gold-tellurium districts. There is no trace of it at Nagyag, and, so far as I know, none, or in any event very little, at Kalgoorlie and Hauraki.

gold-veins of Schemnitz and the old lead-silver veins of Clausthal; between Zacatecas, Pachuca, etc., in Mexico, and the "noble" quartz-formation of Freiberg, etc. By reason of these mineralogical arguments, Prof. R. Beck, in his new treatise,* does not separate the older and younger vein-groups, but describes them together in categories determined by their mineralogical character, such as the pyritous lead-formation, the carbonate-spathic lead-formation, the barytic lead-formation, the precious (silver) quartz-formation, the noble silver-copper formation, etc.

In some cases it is doubtful whether veins should be reckoned as belonging to the older or the younger group. For instance, the deposits of Pontgibaud, in central France, show, on the one hand, the character of the old galena-veins, but lie, on the other hand, not far from the late eruptives of Auvergne, and parallel with the volcanic fissure of that field.

As L. de Launay has pointed out, it is quite possible that the older and newer gold-silver-lead-veins have a mutual relation somewhat like that of the formerly so-called "old" and "young" eruptives, which are now distinguished as deep or outflowing, their structural differences being ascribed to crystallization at different depths. To this subject I shall recur later.

Source of the Ore.—We may now inquire, Whence comes the ore of these veins?

For the older as well as the younger ones, we may declare that a clear genetic connection with eruptive rocks can be established. In some eruptive districts the latest eruptives of the series exposed are even later than the ore-veins; hence the formation of the latter must have occurred during the eruptive epoch.

Partly for this reason, and partly because of the fact that, on the whole, the veins are generally independent of the petrographic nature of the country-rock,† I think we are warranted, in this department also, in assuming, as a working-hypothesis, that the ore-material was extracted from a magma. With regard to the younger veins especially, we must keep in mind a possible extraction from a laccolitic magma in depth.

---

* *Lehre von den Erzlagerstätten*, 1901.

† In many cases there is a dependence on the country-rock, the nature of which has favored ore-deposition—as, for instance, in the fahlbands of Kongsberg.

In support of this hypothesis, we may cite the transitional or intermediate occurrences between the cassiterite- and the silver-lead-veins. Thus, in Cornwall, the tin-, the tin-copper- and the galena-veins are so closely related topographically and geologically that a common origin must be assumed for them. The same is true of the cassiterite-veins and the various silver-lead ore-formations of the *Erzgebirge;* and the peculiar tin-bearing silver-lead veins of Bolivia may be recalled in this connection.

These intermediate groups warrant the conclusion that there can have been no absolute essential difference between the genesis of the cassiterite- and that of the silver-lead-veins. If the tin-veins are to be explained by magmatic extraction, the silver-lead veins may not be attributable to the work of underground water.

We refer, also, to a recent paper by E. Hussak,* describing an auriferous pyritic quartz-bed-vein at Passagem in Brazil, and asserting that this vein is to be considered as an ultra-acid granitic apophyse.

Between the ordinary quartz-veins, deposited from aqueous solutions (and at high temperature), and the granitic apophyses, rich in aqueous solution and highly siliceous, there seem to be gradual transitionary types.

We may also recall the fact that ore-veins often continue to a great depth. As will be shown later on, mining is carried on in many places at a depth of not merely 0.75 to 1.25 kilom., but, in fact, as referred to the *original* surface, 3, 4, 5, perhaps 6 kilom.

The minerals in veins and the alterations of country-rocks show, in many cases, that the solutions in the vein-fissures were specially rich in carbonic acid and compounds of sulphur (hydrogen and alkaline sulphides, sulphates, etc.), and to these is often added an aqueous solution of silicic acid. As factors in magmatic extraction for such cases we would assume, therefore, water, carbonic acid, and compounds of sulphur, and, in general, not hydrofluoric or hydrochloric acid.

Copper-Ore Deposits.—The copper-ore veins in or near eruptive rocks (*e.g.*, Butte, Mont., and Cornwall), and also the quicksilver-deposits, permit the adoption of a similar genetic hypothesis.

---

* *Zeitsch. f. prakt. Geol.*, 1898, p. 345.

Conclusions.—That the ore-deposits first mentioned above, viz., the titanic iron-ores in gabbro, the chromite-occurrences in peridotites, the nickel-pyrrhotite deposits in gabbro, etc., were formed by magmatic extraction, I think I have scientifically proved beyond doubt; and I believe that the magmatic-extraction theory advanced for the cassiterite- and apatite-veins is in its main proposition correct. For the ore-deposits subsequently considered—the contact-deposits, the pyritic deposits, the gold-veins, silver-lead veins, copper-ore veins, etc.—the views here offered become confessedly more and more hypothetical. But they have much in their favor; and even if, following in particular the French observers, I have here ascribed to magmatic-extraction too great a significance, I believe, nevertheless, that the hypothesis is worthy of thorough scientific discussion.

At the same time, I wish to add emphatically that, beyond doubt, numerous ore-deposits may have been formed by the action of underground waters, so comprehensively investigated and described by Van Hise; *e.g.*, many deposits of iron- and manganese-ores; the veins of nickel silicate (garnierite); pretty certainly also the native copper of Lake Superior; and many other occurrences.

The precise tracing of the boundary between eruptive after-action and the work of the underground waters is a labor for the future.

III. The Nature of the Ore-Solutions in Vein-Fissures, and the Metasomatic Alterations along the Ore-Veins.

The composition of these solutions may be deduced: (1) from the association of minerals in veins, and their relative order of individualization (Breithaupt's "paragenesis"); and (2) from the alteration of the country-rock proceeding from the vein-fissures.

The Association of Vein-Minerals.

Upon a knowledge of the quantitative relations among the various minerals which crystallized from the same solution we may base a conception of the physico-chemical mass-actions obtaining in the solution. For example, if a vein consists chiefly of calcite, with a little silver-glance, the silver, as well as the calcium, must have been present originally as $AgHCO_3$

and $CaH_2(CO_3)_2$ respectively, in an aqueous solution of carbonic acid, from which it is pretty certain that the silver was precipitated by hydrogen sulphide. Such a case is furnished by the deposits of Kongsberg, Norway.*

By parallel investigations of the paragenesis of the veins and the metasomatism of the country-rock, supported by experiments in mineral synthesis, the chemical nature of vein-solutions can be fairly well determined. The data at our disposal are now so abundant that this question must soon be ripe for final scientific decision.

Deposition of the Vein-Minerals.

These have generally crystallized under high pressure and somewhat elevated temperature. Under present conditions a depth of 1 kilom. in the earth's crust represents an increase of about 275 atm. in pressure, and 30° C. in temperature. In many ore-veins, as will be shown later, it can be shown that the minerals were formed at a depth below the original surface of 3, 4, or 5 kilom., or perhaps more. If we assume 4 kilom., and conditions like those of the present day, there must have been a pressure of about 1000 atm., and a temperature about 120° C. higher than at the surface.

But it must be considered that in the exceedingly numerous deposits connected in some way with eruptive processes, and often, indeed, formed in the later periods of the eruptive activity, the nearness of the igneous rocks must have caused an increase of temperature (and also of pressure ?). This is often so great as to exceed for heavy compounds the "critical temperature," as shown for a few substances in the following list.

Critical Temperatures.

	Deg. C.		Deg. C.
H_2O,	364	HCl,	52
H_2S,	100	$AsCl_3$,	356
CO_2,	31	$SiCl_4$,	230
CO, (about)	140	$SnCl_4$,	319
SO_2,	157	$TiCl_4$,	358

We note especially that the critical temperature of water occurs at 364° (or, according to earlier determinations, 375°)—

* See *Zeitsch. f. prakt. Geologie* for April and May, 1899. Concerning the solubility of silver carbonate as $AgHCO_3$ in water containing free carbonic acid, see a treatise by Chr. A. Münster, cited by P. Krusch, *Id.*, 1896, p. 103.

a temperature which certainly must have been exceeded by magmatic solutions at the moment of leaving the magma. In their upward course—especially determined, perhaps, by their lower specific gravity—the solutions cool; and (partly by virtue of this cooling, and partly through the encountering of various mutually reacting substances) the minerals are successively precipitated.

Alteration of the Country-Rock.

The scientific study of this phenomenon of vein-walls was begun in the '40s by Elie de Beaumont, A. Daubrée and others; yet Waldemar Lindgren's recent admirable paper* gives us for the first time a systematic scientific summary of the transformations which it involves. Mr. Lindgren's classification of veins according to metasomatic processes I here condense for convenient reference.

(1) Topaz-cassiterite; (2) scapolitic apatite; (3) tourmalinic gold-copper; (4) biotitic gold-copper; (5) propylitic gold and silver; (6) fluoritic gold-tellurium; (7) sericitic and kaolinic gold and silver; (8) sericitic and calcitic gold and silver; (9) silicic and calcitic quicksilver; (10) sericitic copper-silver; (11) silicic and dolomitic silver-lead; (12) sideritic silver-lead; (13) sericitic silver-lead; (14) zeolitic copper and silver.

Having busied myself somewhat with this class of problems, I will take the liberty to include here my attempt at a classification of the metasomatic processes caused by ore-solutions.†

Classification of Metasomatic Alterations.

1. Alterations forming greisen, mica-rock, cassiterite-rock, tourmaline-rock, topaz-rock, etc.
2. Scapolitization.
3. Propylitization (with chloritization, etc.).
4. Kaolinization.
5. Sericitization.

---

* "Metasomatic Processes in Fissure-Veins," *Trans.*, xxx., 578.

† Taken from the manuscript of a half-finished paper which I began to write a year or two ago. But I may refer also to my article in the *Zeitsch. f. prakt. Geologie*, Nos. 4, 11 and 12 of 1895, and No. 12 of 1898.

The term "carbonatization," which was new to me, I took, a few years ago, from W. Lindgren's paper, "Characteristic Features of California Gold-Quartz Veins" (*Bull. Geol. Soc. of Am.*, 1895, vol. vi., p. 221); and I now add, still following Lindgren, the term dolomitization (as a process occurring along ore-veins).

6. Carbonatization (with dolomitization, etc.).
7. Silicification.
8. Zeolitization.
9. Intense contact-metamorphism.

I would mention also the formation of alum-stone; quartz-alunite rocks; quartz-diaspore rocks, etc.;* and also the formation of bauxites, etc. But I do not know that these changes have been anywhere observed in genetic relation with ore-veins.

Between Lindgren's classification and this one previously written, though not published, by myself, there is, on the whole, a striking resemblance. My final heading, "Intense contact-metamorphism," is not included by Lindgren: but I believe that it plays an important part in connection, not, indeed, with the vein-fissures which he discusses, but with the contact-deposits described in a previous part of this paper.

Additional Observations.

To Lindgren's thorough treatise I venture to add, by way of complement and confirmation, a few isolated and fragmentary observations.

Kaolinization.—As is well-known, A. Daubrée† called attention to the fact that many of the principal kaolin-deposits in Cornwall, central France and the *Erzgebirge* accompany the tin-ore deposits of those regions. This may, perhaps, suggest the idea that the formation of kaolin, like that of cassiterite, must be explained in some way by the action of fluorides. Long ago, however, Forchhammer (1835) and Bischoff (1855), followed by many more recent authorities, ascribed kaolinization to the attack of water carrying carbonic acid;‡ and this must be the correct view, for the following reasons: (1) kaolinization is in many cases a surface-process, affected by the weak carbonic-acid solutions of surface-waters; (2) at somewhat greater depths, the feldspars of the rocks are often converted by similarly weak carbonic-acid waters into kaolin, sericite, etc., as well as calcite. Other instances may be given, in which the action of fluorides is excluded.

* See W. Cross, "Geology of Silver Cliff, etc., Colo.," and S. F. Emmons, "The Mines of Custer Co., Colo.," *17th Ann. Rep. U. S. Geol. Sur.*, 1896.

† *Études Synthétiques de Géologie Expérimentale*, 1879; and also in his earlier works.

‡ For the literature of the subject, see under "Kaolin," F. Zirkel's *Lehrb. d. Petrographie*, 1894, vol. iii.

It is notoriously orthoclase which is most frequently converted into kaolin. Forchhammer states the reaction as follows (in the old notation, which I retain):

Orthoclase, ...	Al_2O_3,	K_2O,	$6SiO_2$	
Subtracted, ...		K_2O,	$4SiO_2$	
Added, ...				$2H_2O$
Kaolin, ...	Al_2O_3,		$2SiO_2$,	$2H_2O$

Other feldspars and silicates of alumina, such as hornblende, augite, beryl, topaz, etc., are known to be occasionally converted into kaolin; but the study of the primary kaolin occurrences of granite shows that the potash-feldspar is much more easily or rapidly kaolinized than the silicates of magnesia and iron (magnesia-mica, etc.), while quartz is attacked but very weakly.

A few years ago, near Jösingfjord, at Ekersund-Söggendal, 4 or 5 kilom. from the ilmenite-deposit of Blaafjeld-Storgangen, in southern Norway, a kaolin-deposit in labradorite-rock was discovered, of such importance that it is now worked commercially. The kaolin was formed *in situ* from the labradorite, in which it occurs in pre-glacial fissures. The various stages of the alteration are illustrated by the following table of analyses (hitherto unpublished), some of which, unfortunately, are not complete:

Analyses of Labradorite and the Products of its Kaolinization.

	Labradorite.	Labradorite, Partly Kaolinized. I.	Labradorite, Partly Kaolinized. II.	Massive Kaolin, More or Less Pure. I.	II.	III.	IV.	V.	Normal Composition of Kaolin.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	54.5	50.03	49.16	48.61	48.06	47.83	47.72	46.85	46.50
Al_2O_3	27.0	28.60	29.60	29.45	38.57 (Al_2O_3, Fe_2O_3)	34.53	37.40	37.56	39.56
Fe_2O_3	2.5	1.62	1.88	3.40		1.70	1.59	1.00	0.00
CaO	9.0	4.21	3.47	0.68		0.48	0.23	trace.	0.00
MgO	1.0	2.95	1.67	0.49	undetermined.	0.59	0.11	trace.	0.00
Na_2O	5.0	about 1.00 (Na_2O, K_2O)	undetermined.	undetermined.		undetermined.	0.76	undetermined.	0.00
K_2O	1.0						0.44		0.00
H_2O	...	11.90	13.63	16.38	12.95	13.76	11.66	14.44	13.94
Total	100.0	100.31	(99.41)	(99.01)	(99.58)	(98.89)	99.91	(99.85)	100.00

NOTE.—Labradorite-rock consists overwhelmingly of labrador-feldspar (containing about 56.25 per cent. SiO_2) with a couple of per. cent. of ilmenite and hypersthene, somewhat more richly concentrated here and there in spots. Hence the relatively high percentage of MgO in Analysis I. of labradorite, and of Fe_2O_3 in I. of kaolin.

Taken together with the macroscopic and microscopic study of the transitional stages, these analyses show: (1) that ilmenite and hypersthene resisted attack better than the labrador-feldspar; and (2) that from the latter its alkali-silicates were extracted.

The larger the amount of Na_2O, K_2O, CaO and MgO (with some SiO_2 and Fe_2O_3) removed, the smaller becomes the specific gravity. That of the labradorite unaltered is 2.727; of the slightly kaolinized, 2.666; of impure kaolin, still showing the feldspathic structure (Analysis IV. of kaolin, with 47.72 SiO_2), 2.254; of almost pure kaolin, 2.193 and 2.192; and of the purest kaolin of the district, 2.178. These determinations hold for the porous masses, including the pores: pure non-porous kaolin has a specific gravity of 2.6.

That in this case kaolinization has resulted from the action of carbonic acid waters, follows from the fact that occasionally, though rarely, calcite occurs with the kaolin, while most of the Na_2O, K_2O, CaO and MgO (as soluble carbonates), as well as the dissolved SiO_2, have been entirely removed.

If I correctly understand Lindgren, he seems, on pp. 614 and 664 of his paper, to intimate that stronger agents, such as sulphuric acid, may have operated or co-operated to form kaolin. In my judgment, it is not necessary to assume such stronger agents, especially in view of the well-known kaolinization, by ordinary weathering, of the feldspars of rocks. Moreover, sulphuric and sulphurous acid appear to produce transformations of a different sort (such as alunite, etc).

As already remarked, kaolin occurs in some cassiterite-veins (as well as in their metasomatized wall-rocks), and also in certain districts of sulphide-ores. Examples are found at Nagyag, Puda and other places in Transylvania, where propylitization has been occasionally accompanied, in a subordinate degree, by kaolinization. According to the descriptions of Béla von Inkey and Semper, this kaolinization took place along the veins, and was independent of recent weathering by surface-agencies.*

* See B. v. Inkey's *Nagyág u. Seine Lagerstätten*, Budapest, 1885; and Bergassessor Semper's *Beiträge zur Kenntniss der Goldlagerstätten des Siebenbürgischen Erzgebirges*, in the *Abh. d. preuss. geol. Landesanstalt*, 1900, p. 23. According to Kolebeck's analysis (given in the *Oest. Z. f. B.-u. Hüttenw.*, 1888, and referred to by Lindgren), the so-called kaolin of Nagyag is in reality mostly sericite or sericite

This seems to be true also of the kaolinization of the Cripple Creek district,* where occasionally not only granite but also phonolite and andesitic breccia have been transformed to kaolin. That this is kaolin, and not sericite, Hillebrand's analyses prove.

Again, at Schemnitz, Hungary, according to some accounts, propylitization has been accompanied, here and there, by kaolinization. For additional examples, I refer to Lindgren's paper, under "Sericitic and Kaolinic Gold and Silver Veins," and also to the article "Kaolin" in C. Hintze's *Handbuch der Mineralogie.* On the whole, kaolinization along ore-veins is rather scanty.

We note, then, as the result of many observations, that the formation of greisen (bordering cassiterite-veins), and also propylitization and sericitization, and probably silicification, are accompanied here and there by kaolinization, which, on the other hand, seems to be wholly absent in cases of carbonatization (along ore-veins), or, as Lindgren says (p. 614):

"Wherever abundant carbonates form metasomatically, together with sericite, kaolinite seems to be absent."

Calcite is also, as a rule, wholly absent from the primary kaolin-deposits, formed *in situ* from granite, gneiss, etc. Even in the kaolin-deposit of Ekersund-Söggendal there is scarcely any lime, though the original labradorite-rock carried considerable calcite.

Both kaolinization and carbonatization (or the latter with sericitization) result from the attacks of carbonic acid water, but with this important difference, that in the former, lime, magnesia, potash and soda are almost or quite removed, leaving the silicate of alumina; whereas in the latter, calcite, and generally also the *potash*-alumina silicate, sericite, are deposited or precipitated. This difference is due, pretty certainly, to quantitative variations in the constituents of the attacking solution. Thus, we learn from the weathering of granite, etc., that very weak carbonic-acid water can remove lime, magnesia, alkalies, etc., and produce kaolin; and, on the other hand, it

---

mixed with kaolin. The masses produced by kaolinic transformation, described by Semper as rich in kaolin, calcite and pyrite, probably contain considerable sericite.

* Messrs. Cross and Penrose, in 16*th Ann. Rep. U. S. Geol. Sur.*, Part ii., 1–209.

may be assumed that water rich in dissolved alkaline and earthy carbonates favors carbonatization and accompanying sericitization.

*Comparison Between Cassiterite-Veins and Lead-Sulphide Veins.**—The elder French school drew an absolutely sharp line between the tin-deposits and the sulphide-bearing veins. Some went so far as to divide all ore-veins into two classes: (1) the *filons stannifères*, products of fumaroles in granites; and (2) the *filons sulfurés dites plombifères*, deposited by thermal springs, and supposed by some observers to be always connected with basic rocks. It is true that the typical cassiterite-veins (Cornwall, Saxony, etc.) are, so far as known, connected with acid eruptions exclusively; but the converse proposition, that sulphide-veins are connected with basic rocks exclusively, does not fit the facts. As a single instance, *instar omnium*, we may mention the immense copper-silver-ore deposits in the Butte granite, in Montana.

The division into *filons stannifères* and *plombifères* is quite fitting†—only there are, here as elsewhere in nature, no sharp boundaries, but, on the contrary, gradual transitionary forms.

Among such transitions we may mention the frequent occurrence in cassiterite-veins of arsenopyrite and other sulphide ores; the tin-copper-ore veins in Cornwall; the connection, in the *Erzgebirge* and in Cornwall, between lead-silver veins and cassiterite-veins; also the cassiterite-bearing lead-silver veins of Bolivia, and veins in Tellemarken, Norway, which I have briefly characterized as "cassiterite-veins carrying copper-ore instead of cassiterite." Again, we may point out that tourmaline and other boro-silicates (axinite, datolite, etc.) have often been observed, even in abundance, in veins carrying sulphide copper-ores or gold. The general treatises of A. v. Groddeck‡ and A. W. Stelzner,§ and a series of other publications (some of which Lindgren cites under "Tourmalinic Gold-Copper Veins"), are authorities for this statement. Yet, so far as I am aware, galena-silver-ore veins carrying tourmaline in abundance are not known.

* The groups here indicated under these titles are those named by Daubrée, in his *Études Synthétiques*, etc. (1879), *les filons stannifères* and *les filons sulfurés dites plombifères*.

† Deposits of iron- and manganese-ore are not included in this classification.

‡ *Zeitschr. d. d. geol. Gessellch.*, xxxix., 78, 237 (1887).

§ *Zeitschr. f. prakt. Geol.*, 1897, p. 41.

As a characteristic mineralogical difference between the two classes of veins under consideration (*stannifères* and *plombifères*) we may point out that topaz, so characteristic of the former, has never been observed, either in the ordinary sulphide-ore veins (Freiberg, Clausthal, etc.), or in the tourmaline-bearing veins, whether with sulphide copper-ores or with gold. In the ordinary sulphide-ore veins, moreover, apatite and other primary phosphates are wanting, as is also the lithium-mica, so characteristic of cassiterite-veins.

Comparison Between the Formation of Greisen, etc., and Propylitization, etc.—Turning now to the metasomatism of the vein-walls, we find that topazization and the formation of topaz-greisen are confined exclusively to cassiterite-veins. On the other hand, we never encounter, along these veins, propylitization, sericitization and carbonatization, which belong to the veins of sulphide-ore or gold.

Kaolinization, on the contrary, takes place (although subordinately) here and there alongside of veins of either kind. The same is true of silicification, as illustrating which I may mention the formation of "quartz-rock" alongside of cassiterite-veins; also the silicification (Verkieselung) of the walls of some later gold-veins (as in a part of the Verespatak district, in Transylvania) and of some quicksilver-veins.

Again, here and there along the cassiterite-veins as well as the sulphide-veins, we find the country altered to mica-rocks, which, although not for the two classes mineralogically identical, present so many analogies that they must have been formed under pretty similar conditions. The mica-rock along the cassiterite-veins is petrographically allied to greisen (and tin- or topaz-bearing greisen), topaz-rock, etc., and consists chiefly (or wholly ?) of lithium-mica. On the other hand, at Telemarken, Norway, a biotite-granite is likewise altered to mica-rock, along certain quartz-veins carrying chalcopyrite or bornite; but here the mica, which appears often in large crystals, contains no lithium, being a potash-mica (muscovite). In the same locality, subordinate fissures in the vein-material are often lined with mica crystals (1–2 cm. in diameter), exactly as are the similar fissures in the well-known cassiterite-deposits of Zinnwald, in the *Erzgebirge*.

As in the ordinary alteration to mica-rock and topaz-greisen, so likewise in propylitization with chloritization and sericitization, it is, as a rule, the iron-magnesium-silicates (mica, augite, hornblende) which first (before the feldspars) suffer alteration —in other words, offer the smallest resistance to the attacking solutions. On the other hand, mica, augite and hornblende are more resistant than the feldspars to the processes of alteration which form kaolin.

Concerning the alteration of the later eruptions (andesite, dacite, trachyte, rhyolite, etc., sometimes also basalt) to propylite, I would refer in particular to the well-known monograph of G. F. Becker on the Comstock Lode (1882), and the investigations of B. v. Inkey, Dölter, Judd, Koch, Szabó and many others.*

In propylitization, as is well known, the iron-magnesium silicates (augite, hornblende, mica, etc.) are converted chiefly into chlorite, with sericite, actinolite, epidote, serpentine, iron oxides, spathic carbonates, etc. The feldspars lose their luster; their cleavage is impaired; and they are impregnated with products of decomposition, particularly chlorite, epidote, calcite, etc. Moreover, the re-formation of pyrite is very characteristic; and, as a rule, the further propylitization has progressed, the larger the quantity of pyrite. Becker has shown that this pyrite has been derived from the iron-magnesium silicates and the iron oxides (magnetite, ilmenite, specular hematite) of the original rock, through the action of solutions containing alkaline sulphides or hydrogen sulphide.†

Rosenbusch describes propylitization as "a process of solfataric and thermal‡ alteration." Nearly related to it are chloritization and sericitization. It is confined to later ore-veins, connected with extensive rocks, and is absent in the corresponding veins of earlier origin. Possibly the reason of this difference

* See chapters on propylite in Rosenbusch's *Microsc. Physiogr. d. mass. Gesteine* (1896), ii., pp. 913–917; Zirkel's *Lehrb. d. Petrographie* (1894), ii., pp. 584–595; and on "Propylitic Gold- and Silver-Veins" in Mr. Lindgren's last paper.

† Here we are reminded of the chemical nature of the solutions of the recent quicksilver-deposits at Steamboat Springs, Sulphur Bank, etc. (investigated by Becker and others), where the quicksilver is found combined with a sodium sulphide, HgS, nNa_2S.

‡ SECRETARY'S NOTE.—I understand this term, as used in German, to mean the action of heated aqueous solutions.—R. W. R.

may be that the "old" veins were formed at much greater depths, and hence under much higher pressure, whereby the escape of solutions (and especially the dissolved gases, H_2S, etc.) into the country-rock was hindered. I shall presently return to this point.

A priori, it is natural to conceive the metasomatism along veins has been generally accompanied by a considerable change (now addition, now subtraction) of material. This does indeed occur in some instances, especially in topazization, tourmalinization (with axinitization) and kaolinization; but in many other metasomatic alterations the change of material is relatively insignificant. This is the case in scapolitization; in intense contact-metamorphosis; in many alterations resulting in greisen and mica-rock; and also in propylitization with chloritization and sericitization. How small, in the latter processes, are the chemical differences between the original and the altered rock, I have learned with astonishment from the analyses collected by Lindgren.

Conclusions.—In conclusion, I will attempt to give a summary of the agencies operative in processes of alteration:

1. Topazization, the formation of topaz-greisen, tourmalinization, axinitization, etc., are chiefly due to the action of fluorides—in the two latter cases, of boro-fluorides.

2. Scapolitization is due to re-crystallization under high pressure, with access of a chloride (particularly sodium chloide) solution.*

3. Propylitization is a solfataric and thermal alteration, effected by attacks of hydrogen sulphide or alkaline sulphides, and often also of carbonic acid.

4. Kaolinization, sericitization and carbonatization are produced by the action of waters carrying carbonic acid, or carbonates of alkalies and earths, in variable proportions. (In kaolinization, the waters carry so much carbonic acid that the alkaline and earthy carbonates are nearly or wholly removed, together with the dissolved silica. In sericitization and carbonatization, on the contrary, there is a deposit of potassium silicate or calcium carbonate.)

5. Silicification results from percolation by a solution of silicic acid.

* See, on this subject, *Zeitsch. f. prakt. Geol.*, 1895, pp. 447, 455.

6. Zeolitization is also produced by silicic acid, but under different conditions (probably, as a rule, by a solution containing silicates of sodium, potassium, calcium and aluminum).

7. Intense contact-metamorphism involves a recrystallization under high pressure, with penetration by heated aqueous vapor, and is, *per se*, accompanied by a comparatively subordinate change of material. Sometimes, however, it occurs in connection with ferrification, silicification, tourmalinization or axinitization, etc.

8. The formation of alum-stone or alunite is chiefly effected by the penetration into the rock of a solution of sulphuric or sulphurous acid.

Frequently several of the above agencies operate in combination, rendering the results more complicated.

IV. Differences of Depth in the Original Positions of Epigenetic Deposits; and the Secondary Alterations of Deposits.

The attention of both miners and geologists was long ago drawn to these theoretically interesting and economically important problems; yet only in recent years have they received thorough and comprehensive treatment. The valuable contributions made to the *Transactions* of this Institute by Don, Emmons, Rickard, Posepny, Van Hise, Weed and others, are familiar to its members, as well as the work of R. A. F. Penrose and his associates of the U. S. Geological Survey, and other American observers. Much may be learned from the recent treatise of our celebrated professional colleague, Prof. L. de Launay.*

These two phenomena—namely, the original differences of depth connected with the formation of ore-deposits, and the secondary alterations of such deposits, occurring often, perhaps even millions of years later—are in many cases, as genetic factors, very widely separated; yet it may often be difficult to decide what is to be referred to the primary and what to the secondary process. Partly for this reason, and partly because, as Van

* "Les variations des filons métallifères en profondeur" (*Rev. Gén. des Sci. Pures et Appliquées,* xi., 1900; discussed by P. Krusch in *Zeitsch. f. prakt. Geol.*, Oct., 1900). See also De Launay's *Contribution à l' étude des gites métallifères* in *Ann. d. Mines,* 9 Série, vol. xii., p. 119 (1897).

Hise's last paper shows, the two factors go, in many localities, hand in hand, I think they may be, with advantage, discussed together.

Original Differences of Depth.

In considering the original differences of depth, it must be kept in mind, as De Launay has pointed out in the treatises just cited, that the present surface is, in general, very far below the surface existing at the time of the ore-formation. The geological investigations of recent decades have shown that the work of denudation (or abrasion or erosion) must be measured on a larger scale than was formerly suspected. In the Archean and Algonkian mountain chains (now often removed by this agency down to their base-level), and also in the Paleozoic ranges (showing, as a rule, the effects of extremely energetic denudation, as, for example, the Ural and the Norwegian mountains), the difference between original and present levels is to be generally reckoned, not in such units as 0.1, 0.25, 0.33 or 0.5 kilom., but rather on the scale of 2, 3, 4 or 5 kilom., or even more. Even in the Mesozoic and Tertiary, many denudations of astounding depth have been recognized.*

In many epigenetic ore-deposits of Archean-Algonkian or Paleozoic origin (*e.g.*, Kongsberg, Cornwall, Przibram, the Keweenaw peninsula at Lake Superior) mining has been carried

---

* As instances of great denudation, the following may be named:

On the E. side of the Kristiania fiord, in Norway, this process has removed, (1) a series of Devonian conglomerates and porphyry overflows, with Silurian and Cambrian rocks, of an aggregate thickness (according to W. C. Brögger, *Nyt. Mag. f. Naturv.*, vol. xxxviii., for 1900) of 2500 meters; (2) also a large part of the Archean surface—first, during the long period preceding the Cambrian, and again after the removal of the Cambrian, Silurian and Devonian strata. This thickness must also be measured in thousands of meters; so that we have here at least 4000, perhaps 5000, 6000 or even more meters of thickness removed.

The fiords of the W. coast of Norway are often 1.5, sometimes 2 to 2.25 kilom. more deeply eroded than the adjoining high plateau; and the latter frequently consists of deep eruptives, without any remains of the extensive overflows—showing that on the plateau a very extensive denudation, probably to be measured in kilometers, has taken place.

In the Aspen silver-district, Colo., 5 kilom. of strata (according to Spurr) have been removed by erosion from a range of Tertiary origin. (I quote from Krusch's review of De Launay, *Zeitsch. f. prakt. Geol.*, 1900, p. 317.)

In California, according to Lindgren, denudation has extended to a depth of 500 to 1500 or more meters. So far as I know, this denudation has taken place since the beginning of the Cretaceous period.

Numerous other similar instances could be easily adduced.

to depths of 0.75, 1 to 1.25, and 1.25 to 1.5 kilometers. Taking the depth roughly as 1 kilom., and assuming that in some districts the present surface has been denuded 3, and in others 4, kilom. below the surface at the time of the ore-formation, we may say that mining has reached a depth of 3 to 4 or 4 to 5 kilom. below the original surface.

These figures are, of course, somewhat arbitrary; but modern investigations of the extent of denudation justify us in saying that they are not too high for some districts belonging to the ancient geological periods above named.

It may be observed, also, that in many deposits of deep and geologically old origin, the deepest portions of the mines have shown no change in the nature of the fissure-formation. Occasionally, as at Przibram, Bohemia, and Dolcoath, Cornwall, the richest ore-bodies have been encountered in the deepest mine-workings.

We conclude, then, that, under favorable circumstances, the ore-veins may continue at least to a depth, below the original surface, of 3, 4, 5 or more kilometers.

In opposition to this view, Prof. Beck declares* that he has come to the opinion

> "That ore-veins, and mineral veins generally, can by no means extend to great depths, geologically speaking. . . . Even if we could assume the existence, at a depth between 4000 and 6000 meters, of fissures filled with water, it would be inconceivable that, at that depth, mineral deposits could be made from solutions."

I believe, notwithstanding, that future determinations of the extent of denudation, together with the mining of many deposits to the depth of 1.25, 1.5, or even, perhaps, 2 kilom. below the *present* surface, will prove that Prof. Beck's conclusion is not correct.

It may also be remarked, in passing, that mineral deposits may be made from solutions at above the critical temperature (364° C.) of water—for instance, the deposits of cassiterite, wolframite, apatite, topaz, tourmaline, and even pyrites, in many granite-pegmatite veins.

In his latest treatise, which is rich in new conceptions, De

* *Lehre von den Erzlagerstätten*, 1901, p. 139.

Launay compares ore-deposits occurring relatively near the surface, in less denuded regions, with those deep below the surface in strongly denuded regions. As instances of the former, he takes the quicksilver-deposits, which occur chiefly in recent rocks, near volcanic eruptives, while from older ranges, partly destroyed by erosion, they have disappeared, with other débris. As instances of the latter class, he takes the pyritic deposits (Rõros, Huelva, Schmöllnitz, etc.), which have been found in old mountain-chains or in districts of regional metamorphism, and are to be explained as of deep-seated origin. He also mentions very briefly the lead-silver veins.

Induced by his description, I have already suggested in this paper the hypothesis that the differences between the later gold-silver-lead veins (Nagyág, Comstock, Potosi, etc.) and the old gold and silver-lead veins (Kongsberg, *Erzgebirge*, Harz, Przibram, etc.) may be explained by their formation at different depths. The relative or total absence from the older veins of the propylitization which is so characteristic of the later ones may, perhaps, be due to the fact that hydrogen sulphide (or sodium sulphide), which was a very important factor in this process, could not, under the great pressure due to great depth, make its way from the solutions in the fissures into the country-rock.

The later silver-lead veins are, on the whole, richer in silver than the older ones. This may be connected with the fact, inferred on physico-chemical grounds by Van Hise, that at great depth lead sulphide separates in larger proportion than silver-sulphide or sulpho-salts. According to this view, the precious silver-veins (carrying relatively little galena and zinc-blende) of recent eruptive ranges become, at a very great depth, richer in galena and zinc-blende. This seems to be sometimes the case. (Instances are given further on.)

This hypothetical view is not contradicted by the fact that many of the older silver-lead veins, as at Andreasberg and Kongsberg, are highly "precious"—*i.e.*, relatively poor in galena and zinc-blende; for this character may be due to the small proportion of lead and zinc in the original vein-solutions.

In view of the range *below the original surface* through which mining is carried on, beginning, not at that surface, but already

thousands of meters below it, we may easily see that, in many districts, the directly observable differences in original depth have little significance. For instance, at Kongsberg there is no difference in the character of the veins from the present surface to 0.5–0.75 kilom. below it.

In other districts, however, very important differences of original depth have been established. For instance, these differences were very distinct in many Cornish mines, where the veins carried: (1) at the uppermost level (in the tin-bearing gossan) tin-stone and a little copper-ore (the latter as the result of a secondary process, the original sulphides having been mostly leached out of the gossan); (2) their copper-ore, with some tin-stone (in the Dolcoath mine, to the depth of 0.3 to 0.33 kilom. below the present surface); (3) still deeper, first, a zone of mixed tin-stone and copper-ore, and under that almost exclusively tin-stone. The veins traverse, in depth, chiefly granite; at higher levels, slates. But zones 2 and 3 are not confined to either rock. In this case, then, the tin-stone was originally deposited at a greater depth than the copper-ore.

In many silver-lead-zinc veins there is an increase in the proportion of zinc-blende with depth. The Clausthal veins, and many in Mexico (Pachuca, Zacatecas, etc.) are instances. In the latter, very important differences in the depths of original deposition are often observed. (1) Near the surface are very rich silver-ores (the so-called *colorados*, containing cerussite with chloride, bromide and iodide of silver, and native silver), the richness of which is the result of secondary processes.* (2) Below these, after an intermediate zone of transition, appear for the first time the so-called *negros* ores—galena, silver-glance, silver sulpho-salts, etc.; and (3) in the deep workings, say 0.5 kilom. below the present surface, the so-called *fuego*-ores,† carrying much zinc-blende and galena, with a scanty admixture of true silver-ores. It is possible that the Tertiary Mexican veins have in depth a character resembling that of the older rather than that of the younger group described in a previous part of this paper.

* According to the Mexican geologists and miners at the Paris Exposition of 1900, these ores extend, as a rule, very little below the ground-water level.

† That is, "fire"-ores, or, in other words, smelting-ores. The surface-ores are treated by amalgamation.

With regard to the increase of zinc-blende in depth, which has been observed in many places, I have already observed that Van Hise, in his last paper, concludes upon theoretical grounds that from an ascending solution containing zinc and lead, the zinc sulphide would be deposited lower down than the lead sulphide. In many veins carrying copper and iron sulphides, the richest copper-ores are found at the higher levels. As Emmons and Weed have shown for the Butte district, this is in numerous cases the result of a secondary process. In sundry localities, however, the influence of original differences of depth may be recognized. This is the case, for instance, at Vigsnäs in Norway, where the ore, a fine-grained mixture of chalcopyrite with pyrite, occurs in several (about seven) nearly vertical "stocks." In the upper levels the pyritic mixture carried easily 3 to 4 per cent. of copper; at the depth of 735 meters the thickness of the mass was, on the whole, tolerably well maintained; but the copper-content had sunk to about 1 per cent., or a trifle more.

A corresponding phenomenon is not presented, however, by the flat-lying pyritic masses or "lineals" at Röros, which dip respectively 9°, 9° and 15°, and have been worked in these dips to distances of 1080, 1350 and about 2000 meters.

In the pyritic deposit at Huelva (at Rio Tinto, Tharsis, etc.) the secondary concentration in the "zone of enrichment," immediately below the "iron hat," plays a very important part; but there appears to be, besides, a primary distribution according to which the copper diminishes as depth increases.*

According to many American reports, there are also in the United States and in Chile many known instances of the deposition, from an ascending ore-solution, of pyrite and chalcopyrite, in which the former was, to a considerable extent, deposited deeper than the latter.

Not only in the sulphide-ore deposits, but also in those of iron and manganese oxides, primary differences of depth are recognized. Thus at Romanêche in the Department of Saône et Loire, France, the ore-deposits, occurring in granite, consist of psilomelane (named romanechite by Lacroix, on account of its constant considerable percentage of baryta) and specular

* See *Zeitschr. f. prakt. Geol.*, No. 7, 1899.

hematite, with quartz and heavy spar, a very little fluor-spar, and traces of calcite. The mine is, with one exception, the largest producer of manganese-ore in France. For our present purpose, the interesting feature is the change of proportion, at different levels, between psilomelane and hematite. Above, the psilomelane predominates; going down, the proportion of hematite increases with considerable regularity. During a visit which I made in the summer of 1900, together with my friend and colleague, Prof. L. de Launay, Mr. L. Chamussy, the director of the mine, called our attention to the fact that this relative increase of iron-ore in depth is found in many manganese-deposits. His explanation was, that the solution containing manganese and iron compounds came from below, and the ores were precipitated mainly through oxidation by the oxygen of the air contained in surface-waters; that iron thus oxidizes more easily (*i.e.*, sooner) than manganese,* and therefore, on the whole, the larger proportion of iron-ore would be deposited lower than the manganese. This seems to me quite plausible.†

Secondary Alterations of Ore-Deposits.

Concerning the secondary alterations more or less directly connected with surface agencies, I would observe, first, that such phenomena have very little importance in the Norwegian and Swedish deposits, which are generally found in very solid rocks, such as gabbro, gneiss, granulite, mica-slate, phyllite, etc. The occurrrences of magnetite, specular hematite and ilmenite show, as a rule, no trace whatever of a zone of weathering—except that here and there apatite has been, to a slight extent, leached out. The dense, massive magnetite resists

---

* That from a solution containing protoxides of iron and manganese (*e.g.*, in carbonic-acid water) iron is precipitated by oxidation before manganese has long been known. The literature of the subject is given in my work "*Salten og Ranen*" (1890–91), in which a geological application of this order of precipitation was attempted. See also *Zeitschr. f. prakt. Geol.*, 1894, p. 33, and 1895, p. 39; also "The Chemical Relation of Iron and Manganese in Sedimentary Rocks," by R. A. F. Penrose, *Jour. of Geol.*, 1893, vol. i., p. 356.

† I regret that this contribution must be prepared for publication in such haste that I have not time to obtain by correspondence further details concerning this primary difference of distribution in the manganese-deposits. Nevertheless, I venture to give here the above theoretical explanation.

even denudation, so that, for instance, the extraordinarily large deposit at Kirunawara-Luossawara, in northern Sweden, forms a real "iron mountain," rising about 100 meters above the surrounding rocks. The same is true of the Taberg, a mountain of titanomagnetite-olivinite, in southern Sweden. Even the pyritic deposits, like Röros, Sulitelma, Vigsnäs, etc., and the nickel-pyrrhotite deposits, like Erteli, 5 to 10 meters in thickness, show a zone of weathering seldom more than one or two meters deep. At Fahlun, where the pyritic mass was very wide, the "iron hat" was probably deeper.

This insignificance of the secondary alterations, even in the pyritic deposits, is probably due to two chief causes: (1) that the surface was polished clean by the Quaternary ice-sheet; and (2) that the solidity of the country-rocks has permitted very little circulation of water.*

In sharp contrast stand the thick pyritic deposits of Rio Tinto, etc., in the Huelva district, where the "iron hat" extends to 35–50 meters. Here the Quaternary ice-period was lacking, and the country-rocks were much more porous than in the corresponding Scandinavian formations. Concerning these secondary alterations, I would refer to an earlier work of my own, which is mentioned, among others, in the papers of Messrs. Emmons and Weed. Especially noteworthy here is the re-formation of rich sulphides in the "zone of enrichment," and the very characteristic re-formation in Mass II., at Rio Tinto, of a narrow zone, rich in gold and silver, on the boundary between the "iron hat" and the underlying pyritic mass.

Concerning the chemistry of the secondary alteration of ore-deposits I can add little, in this hasty review of the subject, to the excellent discussions of Don, Emmons, De Launay, Penrose, Van Hise, Weed and others.† Especially interesting are

---

* I know several deep mines in Norway, in which the lowest pump-station is only about 250 meters from the surface. In one of them, water for use in drilling below that level has to be carried down.

† I will only introduce some observations upon the solvent effect of the ferric salts, $Fe_2(SO_4)_3$ and $FeCl_3$, upon sulphide ores. To test this point, I made in November, 1896, the following experiment:

Samples of 6 grammes each of pulverized chalcocite, bornite, chalcopyrite, pyrrhotite and pyrite were separately treated in Erlenmeyer jars, 100 cub. cm. of neutral aqueous solution containing 30 grammes of $FeCl_3$ being poured upon each sample, after which they were allowed to stand quietly at the ordinary

the proofs furnished of late years from North America that secondary alteration often extends far below the ground-water level and the re-formation of sulphides in the zone of enrichment, investigated especially by Emmons and Weed.

I would here refer to the collection of specimens from the gold-district of West Australia which was exhibited last year at Paris under the direction of Mr. A. G. Holroyd. That the gold of many localities had been first dissolved, most probably in $Fe_2(SO_4)_3$, and afterwards precipitated, could be clearly seen in a whole series of specimens.

1. From the zone of weathering in many veins were shown small and exquisitely beautiful crystals of gold, sitting upon

---

house-temperature of about 14° C. After a few weeks the chalcocite was almost entirely dissolved, and the bornite had been very strongly attacked. On the other hand, at the end of nine months the chalcopyrite was affected but slightly, the pyrrhotite a little more, and the pyrite not at all.

At the present time, after the lapse of 4 years and 1 month, the chalcocite and bornite have long been completely dissolved; the pyrrhotite is almost all dissolved; the chalcopyrite has been somewhat further affected (by far not so much as the pyrrhotite), and the pyrite has been attacked, though very slightly. From the first four, and probably also to a small extent from the pyrite, sulphur has separated. The filtrates from the chalcocite and bornite showed with $BaCl_2$ a weak trace of H_2SO_4; that of the chalcopyrite a somewhat stronger trace; and that of the pyrite a trace stronger still, yet, after all, amounting to little. The formula is:

$Cu_2S + 4FeCl_3 = 2CuCl_2 + 4FeCl_2 + S$, or $Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S$.

Weed gives the formula thus:

$Cu_2S + 5Fe_2(SO_4)_3 + 4H_2O = 2CuSO_4 + 10FeSO_4 + 4H_2SO_4$.

In the reactions with Cu_2S and CuS, however, the sulphur does not appear to be oxidized to sulphuric acid, though this occurs in subordinate degree in the reactions with FeS and FeS_2.

The above experiments were made, as stated, at ordinary house-temperatures. At higher temperatures the process is very much more rapid. I was present in 1893 at an experiment in the Siemens-Halske metallurgical testing-laboratory at Berlin, when pulverized unroasted pyrites from Rio Tinto, containing 3 per cent. of copper and nearly 50 per cent. of sulphur, was stirred in a weakly-acid solution of ferric sulphate (50 grammes of iron to the liter), at 80°–90° C. After 6 hours, the percentage of copper had been reduced to 0.4. Zinc-blende is also attacked, though not as strongly as chalcopyrite. These reactions are metallurgically utilized in the Siemens-Halske electrolysis of copper-ores, and in the present leaching of pyrites at San Domingo, Tharsis, etc., in the Huelva district.

Metallic silver also is very rapidly attacked by $Fe_2(SO_4)_3$. Gold will be considered below.

Pyrite is one of the commonest minerals in sulphide-deposits; its weathering yields $Fe_2(SO_4)_3$, which plays an exceedingly important part in the secondary alteration of ore-deposits, as I have shown in earlier publications.

cobalt-manganese-ore (asbolite), which is unquestionably a secondary mineral, yet older than the gold which has been precipitated upon it.

2. In many samples from gravels or placers, gold could be seen in small breaks in iron-ocher, limonite, etc.

3. Gold appeared also in stalactites, or "drip-stones," consisting chiefly of iron-ocher and calcite. In this case the gold was unquestionably in a ferric solution.

4. Again, gold from various localities was seen as a very thin tarnish, "breathed," as it were, upon the pebbles of the placer-conglomerates.

5. Several tree-roots were exhibited, upon which gold was sitting.* Here the gold had been reduced or precipitated from solution by organic substances.

6. Finally, gold was to be seen, in several cases, in fine cracks in the dried clay of the placers, into which it had percolated while dissolved, to be precipitated as a thin coating upon the clay.

I am aware that series of similar instances have been described already from America, Australia and South Africa; but I have dwelt upon these new exhibits from West Australia because they plainly show that the solubility of gold may play a *quantitatively* important part.†

The same collection showed beautifully the weathering of the telluric gold-veins of Kalgoorlie. The mines, as is well known, carry in depth (down to 1150 feet, in the year 1900) very rich gold-tellurides (calaverite, sylvanite, kalgoorlite, petzite), sometimes in masses of extraordinary weight (50–100 kilog).‡ In the neighborhood of these, the ordinary phenomena of flake-, sheet- and wire-gold are often found, the native gold being sometimes intergrown with the telluride mass, and sometimes independent of it. In the highly oxi-

* The label read: "Great Boulder Main Reef. Root of tree, found at 70-ft. level. Two pieces of wood, with gold-deposition. (Very rare.) W. A."

† The platinum metals, on the contrary, are to be regarded as practically insoluble by the chemical reagents encountered in nature. See note on p. 131.

‡ I will not enter here upon the discussion of so many years' standing concerning the "mechanical" *vs.* the "chemical" origin of gold-nuggets in placers. (Notwithstanding the solubility of gold, I adhere to the "mechanical" explanation.) But I may say, in passing, that in West Australia the masses of gold-tellurium found in the veins are as large as the placer-nuggets of other regions.

dized upper vein-zones, the gold-tellurides have been entirely decomposed, metallic gold and derivative compounds of tellurium being formed,* and this metallic gold, appropriately called "sponge-gold," "mustard-gold," etc., could be easily distinguished by its peculiar structure from the native gold occurring in depth. This is an indication that the deep native gold is not a secondary formation from gold-telluride, but a primary metallic precipitate. Secondary alteration thus helps us to decide a question which has been discussed for many years, especially in Austria-Hungary, where each of the views just stated has been held by many observers.†

It is well known that in numerous ore-deposits, all over the world, unusually rich ore-bodies have been formed by secondary processes more or less directly connected with the surface. We need mention only Pachuca and Zacatecas, in Mexico; Pasco, in Peru; Potosí and Oruro, in Bolivia; Chañarcillo,‡ in Chile; Broken Hill, in Australia; Mednorudjansk, in the Ural, etc. Our knowledge of the secondary formation of very rich bonanzas is now specially enlarged by the investigations of Emmons and Weed on secondary sulphide-enrichments below the ground-water level, as at Butte, Montana.

Since in the development of science it has been so often seen that new ideas or impulses are liable to be overestimated, I will here add that there are innumerable rich "shoots," "chimneys," "*edle Säulen*," "*Adelsvorschübe*," "bonanzas," etc., which have nothing to do with secondary processes, being of exclusively primary character, and dependent upon the laws which governed the original ore-deposition. I may cite as examples Kongsberg, Andreasberg, Schemnitz, the rich shoots in the Transylvanian gold-veins, etc. And my study of the literature

* The same is known to be true of Cripple Creek.

† On other grounds, I have formerly expressed my adherence to the latter view—namely, the primary character of the ordinary native gold of the deep zones. See *Zeitschr. f. prakt. Geol.*, 1898, p. 418; 1899, pp. 179–180.

‡ See F. A. Moesta, *Ueber das Vorkommen der Chlor-, Brom- und Jodverbindungen, u. s. w., besonders in Chili* (1870). He points out that at the outcrop of the silver-veins of Chañarcillo, etc., the relative proportions of chlorine, bromine and iodine to one another are about the same as in sea-water, to the percolation of which he attributes the formation of these haloids. The explanation given by R. A. F. Penrose (*Jour. of Geol.*, vol. ii. (1894), p. 34, for the presence of silver-haloids in the arid regions, which connect them with neighboring salt lakes and marshes, seems to me more acceptable.

of the Comstock lode has given me the impression that its famous bonanzas were of primary, not secondary, origin.

The question, What is of primary and what of secondary nature? will doubtless long remain an interesting and often difficult problem for discussion.

Postscript.

The foregoing contribution is in many respects much less complete and more fragmentary than I would have it. If, with some hesitation on that account, I have decided notwithstanding to send it to the Institute, it is in the hope that its defects of form will be judged in the light of the fact stated in the introduction, that the manuscript was begun on the 3d and finished on the 31st of December.

I close this work of mine on the last day of the nineteenth century, with a miner's hail, "*Glück Auf!*" to my numerous American colleagues, unknown to me personally, yet well known through their scientific labors, and held in high esteem. Undoubtedly the new century will fill up many defects and solve innumerable riddles and doubts in the science of ore-deposits.

The Rôle of the Igneous Rocks in the Formation of Veins.

BY J. F. KEMP, NEW YORK CITY.

(Richmond Meeting, February, 1901.)

CONTENTS.

INTRODUCTION.

THE saying that "of all the known regions of the universe, the most unsafe to reason about is that which is under our feet,"* might well be the motto of the present paper, in view of the writer's profound appreciation of the difficulties and uncertainties of the subject. In such a field, the temptation is very strong to announce a probable proposition, and then to defend it with a loyalty insensibly graduating into partisanship. Conscious of this danger, the writer has endeavored to maintain an impartial and candid form of statement, though others may feel that he has not been wholly successful.

The subject, as here considered, falls naturally into two divisions. In the first, the competence of igneous magmas to supply both the contents of veins and the solutions which are the common carriers of the minerals is set forth. In the second, the phenomena and the more or less current conceptions of the groundwater are taken up.

This paper is limited to "veins," as the term is ordinarily understood. It practically excludes the common deposits of those metals which appear in appreciable percentages in F. W. Clarke's latest estimated composition of the earth,† namely, Al, 8.16; Fe, 4.64; Ti, 0.41; Mn, 0.07; Cr, 0.01; Ni, 0.01. Of these, iron and manganese are admittedly favorable subjects for circulating meteoric waters, which are conceded to be of themselves effective in the outer 1000 to 2000 ft. of the thickness of the earth's crust. It is one thing, for example, that deposits of iron-ore in the Lake Superior region should result from the rearrangements of iron and silica in a rock which contains 15 to 25 per cent. of the former, and quite a different thing for the less common metals, and above all the precious

---

* Fisher's *Physics of the Earth's Crust*, p. 89.

† *Bulletin of the U. S. Geological Survey*, No. 168, p. 15.

metals, to be concentrated in veins from what we have reason to believe is a condition of excessively sparse dissemination in compact rocks. Experience gained with the former conditions should not be unduly influential in the study of the latter.

Of the commoner metals cited above, iron (with titanium), chromium, nickel and perhaps aluminum are at times abundant enough in the original minerals of igneous rocks to constitute ores.

It may be interesting and valuable as an aid in establishing a correct perspective to note the relative proportions of the ordinary metals in the product of the United States for 1898, the latest year for which statistics have been furnished by the U. S. Geological Survey. Reducing the weights to grammes, and taking the weight of the gold-product as unity, the ratios are found to be as follows: Iron, 120,950; copper, 2487; lead, 2098; zinc, 1090; aluminum, 26; silver, 22; quicksilver, 11. This calculation would be more significant if it covered the product of the world; but the necessary data are not available. It affords, however, within limits, a certain conception of the relative abundance of the several metals.

I. The Competence of the Igneous Rocks to Supply the Materials of Veins.

The Demonstrated Presence of the Metals in the Igneous Rocks.

Within recent years many assays of rocks have been made, in order to throw some light on the source of the metals in ores. In selecting the samples for analysis, certain precautions are essential. Fresh rock must be taken; and the possible impregnation with small amounts of infiltrated metals must be avoided, or else the significance of the results will be vitiated. The amounts to be measured are excessively small, and their determination taxes the resources of the chemist to the utmost. For example, one ounce to the ton means $\frac{1}{320}$ of 1 per cent.; and in some dry assays even fractions of a grain—there being 480 grains to the ounce—are determined. Reagents (particularly the litharge used in dry assays for gold and silver) must be pure to the last degree.

All these precautions have been observed, however, in a large number of cases; and a very considerable amount of

trustworthy data has been accumulated, going to show that the common metals are certainly present in igneous rocks, and that one or another of them is contained in nearly all the commoner igneous types (acid, intermediate and basic). Some metals seem to favor one rock and some another—a feature which has been treated at some length by De Launay* and Vogt,† and more briefly summarized by the writer.‡ It has been shown also that the ferro-magnesian silicates are richer in the metals than is the rock as a whole, and that they are probable sources of the metals. The metals appear in them either as bases or as metallic inclusions.

It was the original purpose of the writer to tabulate these results; but the mass of data was found to be too large to be practicably handled in this way, and therefore only the above general statements are made. Many references, however, are given in the work last cited.

We must bear in mind that the results of these assays and analyses have, to a large extent, but general interest and application. Only from the point of view of a lateral-secretionist of the Sandberger type does it follow that the ores in a vein have been derived from the wall-rocks which are accessible for assay. In instances like Butte, Mont., in which two sets of veins, of greatly contrasted mineral contents, are found in the same country-rock, other sources must be assumed for at least one series of them, no matter what are the theoretical predilections of the observer. Nevertheless, it is a fact of the greatest importance that the presence of the metals in igneous rocks has been established. Not all igneous rocks have yielded such results on assay. The general experience has been that when samples of several varieties have been collected in a given district, some have proved barren; and it must be admitted that some negative results have been obtained. As a rule, however, they are decidedly fewer than the positive results. It is likewise true that not all igneous districts contain veins of ore. Great areas of surface-flows, such as the basalt plains of Idaho, Oregon and Washington, are notably barren, probably for reasons that will be subsequently advanced.

---

* L. De Launay, *Annales des Mines*, August, 1897. Reprint, p. 45.

† J. H. L. Vogt, *Zeitsch. für prakt. Geologie*, vi., 225 (1898).

‡ J. F. Kemp, *Ore-Deposits of the United States and Canada.* Third edition (1900), p. 35.

The elements of the minerals which form the common varieties of gangue are found in all the igneous rocks, and in the sedimentary rocks as well. Quartz is much the commonest of the gangue-minerals, and silica is universally present in the rocks. Calcite and fluorite may derive their calcium from an equally wide range of rocks and minerals. Barium and strontium are "understudies" of calcium, and available iron for siderite is present on every hand. Where rock, in a stage of greater or less alteration, forms the gangue, it has no special significance in this connection; and gangue-minerals other than those cited are relatively uncommon and unimportant.

The Presence of the Metals in the Sedimentary and Metamorphic Rocks.

Wherever the metals are found in the sedimentary or metamorphic rocks, it is logically necessary to refer them to original sources in the igneous rocks, from which they have been derived either by solution or abrasion.* In the former case, the processes of introduction are essentially those to be subsequently discussed; in the latter, except in the case of placers (which are negligible, in this connection, on account of their small amount), the distribution of the metals is extremely sparse. If we begin with a rock which contains but hundredths or thousandths of 1 per cent., and imagine it broken up by the processes of erosion, its minerals subject to solution and dispersion, and to commingling with foreign matter,—or, if they are heavy, to concentration in placers,—the resulting sediment is a less favorable source of supply for migrating solutions than was the original igneous rock. The assays and analyses which have been made confirm this general statement, but they are hardly as abundant, taking the world over, as are those which have been prepared of the igneous rocks. An exception is the really remarkable work by J. R. Don† in Australia.

In making assays and analyses of sedimentary and metamorphic rocks, it is important to observe the same precautions as were outlined for the igneous rocks; and, in interpreting

---

* *Ore-Deposits of the United States and Canada.* Third edition, p. 32.

† *Trans.*, xxvii., 564.

them, secondary impregnation must be guarded against. The following brief summary of the results of several workers will give an idea of the evidence in hand. Dr. Don has made and tabulated a vast number of analyses of the wall-rocks, chiefly sedimentary, of the Australian gold-veins. He was able to determine the presence of gold in fractions of a grain per ton of rock in a large number; but his tests indicated that only those rocks which also contained pyrites gave any returns for gold.* There is, therefore, the presumption that the gold and pyrites were introduced as an impregnation; pyrites not being a mineral favorable to sedimentation. Mr. Winslow,† in connection with his most valuable investigations of the lead- and zinc-deposits of Missouri, engaged Mr. J. D. Robertson to prepare a series of analyses of the rocks of Missouri, both sedimentary and igneous, for lead and zinc. The samples were taken in, near and remote from mines, and in not a few cases amounts were found equal to several thousandths of one per cent. When, however, we compare the analyses of the sediments with those of the igneous rocks, we find that the latter, as a rule, are by one place of decimals richer than the former, and to that extent are, generally speaking, more favorable sources of the metals. These results justify the statement made above that erosion and sedimentation tend to disperse the original metallic contents of the igneous rocks, and to place them in conditions less favorable for concentration by solution.

With regard to the metamorphic rocks especially, it may be said that increasing experience and more accurate knowledge have tended to prove the presence among them of crushed and sheared igneous types, whose foliation is of mechanical origin. Considered as favorable sources of the metals, the same remarks would apply to them as those already made regarding the unaltered igneous rocks. A good illustration is the gold-belt of the Southern States, which is now recognized to embrace amid its schistose types a very large proportion which are of this original character.

---

* It may be again remarked that a grain is $\frac{1}{480}$ of an ounce, and that these values were therefore thousandths and tens of thousandths of an ounce per ton. If one thirty-thousandth of this remote decimal is then calculated, the values in true decimals will be given. They are almost inconceivably small.

† Arthur Winslow. *Geol. Surv. of Mo.*, vol. vii., p. 479.

Conclusions.—Sedimentary rocks are far less favorable sources of the metals than are igneous; but the statement must not be interpreted as a law, though preponderating experience justifies it. Omitting the metals excluded in the opening paragraphs, sedimentary districts not associated with igneous rocks are, as a matter of experience, pre-eminently barren. The lead- and zinc-deposits of the Mississippi valley are almost the only important exceptions which can be suggested, and of these it is fair to say that increasing observation gives some ground for connecting them with dislocations, certainly in southwest Missouri, and to a less degree, perhaps, in southeast Missouri, and for favoring the views which have been especially advocated in recent years by W. P. Jenney. The ores are, however, confessedly hard problems. Concentration from the neighboring wall-rock has been upheld in the case of the veins of the Upper Mississippi, more especially within a year past, by C. R. Van Hise.* Although there is no known occurrence of igneous intrusions in the two regions cited, or in the gash-vein district of Wisconsin, yet it is true that peridotites have been discovered with the lean veins of western Kentucky,† and rocks of this type have elsewhere been found in regions where no eruptives were suspected or anticipated on the basis of the local geology.‡ In the larger lead- and zinc-districts, however, there is no reason, based on observation, for thinking that such rocks are present; and in the present state of our knowledge, these districts must be considered as exceptions to the general rule.

The Abundance in Igneous Rocks of Vapors or Dissociated Gases which will Yield Water on Emission and Cooling.

The ordinary analyses of cold samples of igneous rocks are of little if any value as an indication of the vapors and gases which were present in the hot, fused magma. The observer must turn to active volcanoes and streams of molten lava for his evidence; and from these we may judge of the composition of intruded masses of rock which never reach the surface.

* "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 103 (p. 77 of pamphlet edition).

† J. S. Diller. Mica-peridotite from Kentucky. *Amer. Jour. Sci.*, Oct., 1892, 286.

‡ For example, at Syracuse, Manheim and Ithaca, N. Y.

Practically all students of volcanic phenomena are agreed that steam and its dissociated representatives in the molten rock are the chief, if not the only cause of eruption. The paper by Prof. J. H. L. Vogt, presented at this meeting,* discusses at some length the condition of water in the fused rock. All observers are agreed that the first eruption at any volcanic vent must be caused by the steam which is brought up with the lava from the depths of the earth; but there is a very general disposition to refer the subsequent outbreaks to meteoric or oceanic waters, which percolate through the rocks near the vent, and which in some way become involved in the molten rock. When the pressure produced by them becomes sufficient, an eruption occurs.

It is very generally admitted to be inconceivable that water from any outside source should be able to follow cavities larger than capillary size through solid rock, heated nearly to fusion, to and into molten rock at a temperature of over 2000° F. Any water entering even the outer and moderately heated solid rock would be evaporated and driven outward. It is necessary therefore to fall back on the capillary conduits, through which to introduce into the magma the accessions of water. In order to prove the possibility of this introduction, recourse is had to Daubrée's famous experiment, which has, however, been shown by Osmond Fisher† to have no bearing on the case in point. Daubrée‡ took a slab of sandstone, two c.m. (about 0.8 in.) thick, and cemented it between an air-chamber below, and a chamber above which could be filled with water. The temperature of the lower chamber was raised until the air-pressure was about two atmospheres. The water from the upper chamber was drawn down by capillary attraction, even against this pressure of two atmospheres, and moistened the under side of the slab. It is evident from this that capillary attraction can draw water downward against a pressure; but, as Fisher acutely remarks, the capillary force was effective because it operated toward a free air space. In fact, it is only under these conditions that the difference in surface-tension, which is the real cause of capillary movement, appears between the air and

---

* "Problems in the Geology of Ore-Deposits," *ante*, p. 125.

† *Physics of the Earth's Crust*, pp. 91, 92. ‡ *Géologie expérimentale*, p. 236.

water on the one side and the water and walls on the other. The experiment gives no ground for thinking that water would move through the heated walls confining a reservoir of molten rock and become involved in the latter. There is also some uncertainty about the efficiency of capillary force in rocks which are under great pressure. As I learn from my colleague, Professor R. S. Woodward, no assumptions of its efficiency are based on experimental data.

Again, active volcanoes are known, such as Cotopaxi in Ecuador, which are nearly 20,000 feet above sea-level. They must draw on reservoirs below tide, and yet even at tide-level cavities in the rocks, through which water might reach the magma, will have become impossible by reason of the pressure.

It would therefore seem necessary to believe that the ejected steam and other vapors of lavas have been brought up with them from the depths; but it is only fair to say that many think otherwise, although apparently without careful analysis of the problem. Of the abundance of the vapors there can be no question. They often exceed in volume the lava itself. The question of their origin only affects in a minor way the argument to be subsequently made regarding the cause of movement of the groundwater.

Beyond question, intruded sheets and laccolites are provided with gases similar in all respects to surface-flows; but, in the nature of the case, the gases are yielded much more gradually, and through longer periods of time. They undoubtedly continue to appear until the rock is nearly as cold as the boiling-point of water at the depth at which they stand. It must be admitted that the hot vapors and waters yielded by an intrusion under these circumstances are extremely vigorous chemical reagents* and are incomparably superior to the ordinary groundwater, even when the latter exists in any serious amount below 1500 to 2000 ft. It is also important to remark that the presence of even a very small dike in any region is proof of the existence of a relatively very large reservoir of igneous rock, at some point beneath the surface, and at unknown but not great depth.

---

* Regarding this point, a very valuable paper is that of A. C. Lane, *Bulletin Geol. Soc. Amer.*, v., 259.

The Sequence of Eruptions.

One of the most interesting features of eruptive districts is the sequence of the eruptive rocks. One kind of rock has followed another until, in some instances, a considerable list can be made up. All will recall von Richthofen's observations on the Pacific coast in the late sixties, which led him to infer that eruptions habitually begin with rocks of medium acidity, pass then through a series with increasing silica up to rhyolite, and terminate with basalts. Increasing observation has shown many exceptions to this simple rule; but of the general fact that molten rocks are poured out one after another from what would appear to be a common reservoir, there is no question; and students of the subject have been more and more disposed to explain them by a breaking up of some original parent magma of intermediate composition into the several diverse products.

This succession of eruptions holds good in many localities of extensive vein-formation. At Butte, Montana, for example, a basic granite was followed by an acid granite, and both by quartz-porphyry, with which latter the introduction of the ores seems to have had some connection. After the ores had been deposited, a great outbreak of rhyolite took place, with no attendant vein-formation. At present the quartz-porphyry is by far the least extensive of them all, and forms but a few minor dikes; yet it is quite possible that it may represent some greater intruded mass, far below, from which the ores have come; and for the very reason that it is visible in small amount it may be the most important of all the rocks in connection with the genesis of the ores.

Again, for example, at Douglass Island, Alaska, albite-diorite (sodium-syenite) and gabbro have been identified by G. F. Becker in the order of their outbreak through slates; but it was only just before or along with the intrusion of a small dike of analcite-basalt that the ore entered. On the Comstock, we find a considerable variety of eruptives in sequence. There is a decided difference of interpretation between Mr. Becker, on the one side, and Messrs. Hague and Iddings on the other; but if the latter are correct in considering Mr. Becker's "later diabase" as the same as the "basalt," which is the youngest eruptive, then it was after the intrusion of the "black dike"

of diabase or basalt which is met in depth, that the ores came in along a line of faulting. At Mercur, Utah, a great stratum of carboniferous limestone was penetrated by a sheet of quartz-porphyry, which itself forked into two thin prolongations. Immediately beneath the lower fork of the sheet are silver ores, after the deposition of which an interval ensued. Later on, gold-ores were deposited beneath the upper fork, having been introduced, as is thought by J. E. Spurr, through the influence of a laccolite, assumed to exist in depth.

Dikes may not at first be evident in mines—as was the case in the Ontario at Park City, Utah. In the early work the vein apparently filled a fissure in quartzite, but in depth a dike was met, which formed one of the walls.

Over and over succeeding eruptions have taken place, and then at some stage (usually after a minor intrusion, so far as the exposures give the observer an indication) the ores were introduced, and one may not be able to say whether they came in with or just after it. It is thus evident that some eruptive rocks are unfavorable in themselves, or unfavorably situated in their present positions, for vein-formation, and that one may appear later whose advent is a signal for the ores to enter.

The Sequence of Vein-Formations.

There are also cases of successive and contrasted vein-formation. More than fifteen years ago R. C. Hills recognized three sets of veins in the San Juan region of Colorado, each with different ores; and the recent work on the Telluride quadrangle of the U. S. Geological Survey has shown in detail many of the structural relations.* There are in this district four sets of fissures, but only one carries the ores—a remarkable state of things if the ores are due to the universal circulation of the groundwater. In one instance, the Smuggler vein is faulted by the Pandora, a later vein which does not carry ores sufficiently rich to be mined profitably.

The district of Freiberg, Saxony, is a very complex case. If we include with it some of the veins of the *Erzgebirge* that lie at a moderate distance, the following groups may be distinguished: *Die Zinnerzgänge; die kiesige Bleierzgänge; die edle Blei-*

* See C. W. Purington, 18*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 745.

erzgänge; and *die edle Quarzformation.* All these are recognized as genetically connected with the great eruptions of granite and porphyry in Carboniferous-Permian times. There are, in addition, three other varieties of veins which have usually been considered as later, and even middle Tertiary, viz., *die Kobaltsilbererzgänge; die barytische Bleierzgänge;* and *die Eisenmanganerzformation.* They have been referred to later eruptions of igneous rocks. K. Dalmer, however, develops* some proofs that the first and third date back before the late Cretaceous, and even into the period of the older series. But the point of interest here is the connection with eruptive rocks, which is emphasized by nearly all observers.

It is often assumed in such cases that new series of fractures have tapped new sources of ores; but the hypothesis is not to be ignored that new intrusions may have been responsible for the change of solutions—and experience thus far gained gives the latter at least equal claims with the former. Indeed, new series of fractures can only go down through practically the same rocks as older ones, unless new material is brought in by igneous intrusion; and hence the second hypothesis, in the absence of proof to the contrary, would seem to have preponderant claims over the first.

Contact-Metamorphism.

The observed facts of contact-metamorphism and the conclusions which have been drawn from them have an important bearing on this question. It is well known that some intruded igneous rocks have exercised a profound influence on the wall-rocks through which they have come, while again other intrusions have produced little or no effect. The results depend very largely on the nature of the walls, earthy limestones and argillaceous strata being the most favorable, and quartzose sandstones the least so. Of the igneous rocks, all kinds, in one place or another, have produced notable results, but the acidic and intermediate are the most efficient. Abundance of dissolved vapors seems to be the essential thing for profound effects, as relatively dry fusion is unfavorable. The intruded igneous rock should also stand in contact with the walls for long periods

* *Zeitsch. für prakt. Geologie,* Jan., 1896, p. 1.

and at a depth reasonably great below the surface. All these points are very much the same as those which have already been stated regarding the igneous rocks as producers of veins.

A divergence of views exists as to the amount of material actually contributed to the metamorphosed rock by the igneous agent. Observers on the continent of Europe have considered the amount to be in some instances large, especially of soda; while from facts noted at Westmoreland, England, where a basaltic tuff is penetrated by granite, a limit of one-twentieth of an inch is set by Alfred Harker for the migration of material. The changes produced in contact-metamorphism are in this instance almost entirely those of rearrangement. All observers must, however, admit the general introduction of fluorine, boron and steam, because the distinctive contact-minerals are characteristically provided with these elements. They are therefore described as *mineralizers*, or as being *pneumatolitic* in their nature. Tourmaline, fluorite, fluoric micas, chondrodite and topaz are illustrations of the resultant minerals; while biotite, garnet, albite, wollastonite, vesuvianite and a number of other silicates are common associates. If, now, ores are found associated with these minerals and along the contacts with igneous intrusions, and not extending far back into the wall-rocks, the inference is well-grounded that they have been derived from the eruptive. In the last paper of Professor Vogt, already cited, the cases of tin-ores and iron-ores to which these views apply are given at length; and in the paper of Mr. Lindgren* copper-deposits of similar nature are cited. Fissured wall-rocks which stand immediately above laccolites rich in mineralizers would be in the situation most favorable for these changes; but opportunities for observation are restricted because the laccolite is only revealed by their removal. When they do persist, however, and are thick, the existence of veins would suggest the presence of the laccolites.

Pegmatites.

Pegmatites have furnished for many years a disputed question. They are beyond doubt connected with great masses of intruded rock, more often with granite than with any other,

* "The Character and Genesis of Certain Contact-Metamorphic Deposits" (Richmond meeting). (See page 226 of present volume.)

and are after-births of the eruptive. Whether they are themselves to be considered as true eruptives, or whether dissolved vapors have played so large a part in their genesis that they are veins rather than dikes, or whether some belong to one of these types and some to the other, does not immediately affect the question now before us—their connection with eruptive rocks being the important point.

Pegmatites usually present the mineralogy of the granites on a very coarse scale, but they have, in addition, more abundant amounts of the pneumatolitic minerals. They may be rich in feldspar and less rich in quartz, or they may be extremely rich in quartz with only subordinate feldspar or other minerals. The writer believes that in some regions of their extensive development all gradations can be found, from granitic mixtures to veins of pure quartz. The north shore of Long Island Sound is a case in point. Pegmatites are abundantly developed in connection with granites, and all grades are shown up to practically pure quartz. The great quartz-vein at Lantern Hill, Mystic, Conn., is one of the largest quartz-veins known, being apparently 1000 ft. wide across the comb-in-comb structure, which is at times pronounced. I think it belongs in the pegmatite series, and is only a huge development of veins of a smaller size which are abundant around Narragansett Bay and elsewhere.* Certain parts of the Lantern Hill quartz show the presence of ferruginous minerals and have yielded on assay a few cents of gold per ton.

The gold-bearing pegmatite of Passagem, Brazil, described by Hussak,† has been referred to by Prof. Vogt. In the Triassic diabase of the Palisades, pegmatite veins richly charged with pyrite are not uncommon. Last summer, the writer spent several days at Copper Mountain, on the Similkameen river, near Princeton, Yale Dist., B. C., and found a great mass of gabbro, shattered along a wide belt. Into the minute fissures bornite had been introduced in some places, and minute veins of pegmatite in others, while in the Copper Cliff and Copper Reef claims, on the banks of the river, a huge pegmatite vein or dike carried here and there large masses of bornite. The

---

* J. F. Kemp, *Bulletin Geol. Soc. Amer.*, x., 372, 1899.

† *Zeitsch. für prakt. Geologie*, October, 1898, p. 345.

bornite impressed the observer as being as much an original mineral in the vein as any of the other components.

In view of the above facts, which could indeed be much amplified, the following statements seem to be justified: Pegmatites are a more or less pronounced pneumatolitic result of igneous intrusion. Pegmatites grade insensibly into quartz-veins. Quartz-veins not visibly associated with pegmatites are open to the same interpretation unless there is positive evidence to the contrary. On the other hand, pegmatites, although widely developed, are but rarely provided with metallic minerals in notable amounts, and the same is true of the quartz-veins visibly associated with them. But it is also true that many regions of great development of pegmatite-veins are devoid of ore-bearing veins, as, for instance, New England, and it is probable that the magmas did not contain the necessary metals for their production.

Frequency of Pneumatolitic Minerals in Veins.

Some of the common gangue-minerals contain those elements which are justly associated with pneumatolitic processes. Of these, fluorite is the most important; and while it cannot be always asserted that it implies the neighborhood of eruptive rocks, it yet creates a presumption in favor of their genetic influence. The gold-ores of Cripple Creek, Colo., and the Potsdam ores of the Black Hills, are cases in point. Lindgren has already emphasized this connection in his extremely valuable paper on "Metasomatic Processes in Fissure-Veins" (*Trans.*, xxx., p. 691, p. 114 of the pamphlet edition,) and therefore it is only cited here in a brief way.

Surface-Flows of Igneous Rock Unfavorable to Vein-Formation.

The vapors contained in surface-flows of igneous rock pass off directly into the atmosphere, and therefore do no geologic work of this character. The most that could be expected of them would be small incrustations in the cracks in their upper and first chilled portions, such as the copper-minerals and specular hematite found in the crevices of Vesuvian lavas. The absence of ore-deposits in flows of this character argues nothing against the efficiency of other forms of igneous rocks.

II. The Groundwater.

The Common Conception of the Groundwater.

The general conception of the groundwater, that has been hitherto held, has involved the existence of a standing body, quite universally present, and at a fairly definite depth below the surface, which depth is characteristic of the particular district. The upper surface is thought to be sharply marked and to be revealed by the boundary between the oxidized or enriched ores and the unaltered sulphides in an ore-body. The supply of water is kept up by the contribution of that portion of the rainfall which neither runs off nor immediately evaporates, but which sinks into the ground, feeds wells and springs, and necessitates pumping in mines. Rocks being more or less porous and crossed by faults, joints and cracks, it has been inferred that the waters continually migrate downward, partly by capillary attraction, partly through small crevices and partly through large ones, until, meeting the hotter interior zones of the earth, they are forced by the head of the descending currents (that is by gravitative stress), reinforced by the loss of density due to accessions of heat, to rise again to the upper world. During their journeys they move laterally as well as downward, pass through vast masses of rock, relieve them of their mineral and metallic contents, and deposit this dissolved material more especially on their upward journey. The fact that we find a great body of standing water not far below the surface in regions of heavy or moderate rainfall would make it necessary, according to this conception, to believe that the rocks are pretty thoroughly saturated with water down to the depths at which the return journey begins; in fact, as Van Hise often expresses it, there exists a sea of the groundwater. Van Hise in particular rejects specifically the igneous rocks as significant contributors either of material or of energy, and expresses, in the premises or propositions which he seeks to establish, his belief that the waters which fill the veins with minerals are meteoric, and that gravity is their motive power. It is fair to add that the conception is a time-honored one, and has found frequent previous expression; but we owe to Van Hise an exceptionally clear and logical exposition of it.

There are, however, grave objections to this conception, and

we may justly examine it in the light of the experience which has been gained in very deep mines and wells, as well as on certain general theoretical grounds.

Experience in Deep Mines and Wells.

Mines exceeding 2000 or 2500 ft. in depth are of extremely modern development. In several important instances of this class, as well as in many mines of smaller depth, it is possible to impound all the water within a short distance, it may be within 500 ft., of the surface. Below this level the workings are dry and, in a few cases, dusty.

The copper-mines on Keweenaw Point are most favorable in their geological structure to the downward passage of water. The shafts, several of which are now between 4000 and 5000 ft. deep, cut a series of sheets of trap and amygdaloid that dip 36° to 39°, and include one or two beds of conglomerate. They are fissured, and at times even brecciated.* As shown by the chart opposite p. 167 of the Report just cited, the North Tamarack Shaft, No. 3, at a depth of 3818 ft. had cut 73 different trap and amygdaloid layers. It is fair to infer that the new shaft which has recently grounded in the Calumet conglomerate at 4760 ft. must have cut correspondingly more. Yet the deep workings of these copper mines are not only dry, but in some cases dusty; and the water is impounded either at the surface or a short distance down the shaft. Such water as trickles down the shafts from the top is occasionally baled out, and water for the drills has to be specially sent down into the headings.

At Calumet, the only water encountered in the deeper workings, or indeed below some such depth as 500 ft., is a highly alkaline variety, tapped in insignificant amounts from occasional fissures. It has a painful effect upon cuts and is avoided as far as possible by the miners. As a whole, the rocks are free from visible water.

Posepny says that the deep workings at Przibram have afforded a similar experience. Below 800 meters there is no water to be raised, because evaporation removes whatever exists there. Much that has been pumped from the levels immediately above 800 meters is doubtless water that has escaped im-

---

* *Geol. Survey of Mich.*, vol. v., part i., p. 112.

pounding nearer the surface, and has followed down the openings made by the mine itself. The deepest workings at Przibram mentioned by Posepny are 1110 meters.*

Experience gained in the deep Cornish tin-mines, like the Dolcoath, would be important in this connection, but at the time of going to press it is not available. Mr. B. B. Lawrence has mentioned, in some informal remarks at this meeting, the Pelican-Dives mine, near Georgetown, Colorado, which has now attained a depth of over 2000 ft. The water has been allowed to follow the workings down and is raised from the bottom, but no more is pumped now than when the bottom sump was located in the upper levels.

The cases cited merely express the general experience of mining engineers, all of whom are aware that, with impounding of the surface-water, increase of depth, especially below 2000 ft., means almost invariably dry workings. Even if the rocks are "dry" in the miner's sense only, and not in the strict scientific sense, if their contributions of water are removed by evaporation so as not to be noted; or if, in a great artificial excavation, far larger than the vast majority of natural waterways, no pumping is necessary, the water in the rocks may be neglected as a producer of veins. The deep mines which are known to be wet, such as those of the Comstock lode, are in regions of expiring vulcanism, as will be emphasized a little further on.

Many mines, especially collieries, have been driven under bodies of water, and even under the sea, and yet they have been but slightly if at all troubled by water, and sometimes have been absolutely free from it. Tight shales, in a sedimentary series, would partly account for this; nevertheless the general experience is worthy of emphasis.

Artesian borings have in a few cases yielded similar testimony. The deep well near Wheeling, West Va., which has been made famous by the measurements of Professor Wm. Hallock on the increase of temperature with descent, reached a depth of 4500 ft. The last water was cased off at 1500 ft., so that for 3000 ft. the hole was dry. In this 3000 ft. the well penetrated shales and some sandstones, both of marine origin. Shales

* *Trans.*, xxiii., 248; xxiv., 971.

are admittedly the least favorable of rocks for circulating waters, but it is a surprising fact that this great section afforded a dry hole.* The Pittsburgh well is still more remarkable. In February, 1897, the well had reached a depth of 5386 ft. It was cased only to 900 ft., or slightly beyond, and for over 4400 ft. was dry. The well penetrated a section similar to that at Wheeling.

On the other hand, the deep wells at Sperenberg, Schladabach and Reibnik, all in Germany, are wet, so far as the published descriptions of the measurements of temperature inform us, but as they were bored with the diamond-drill, it is believed that they were not cased. I have, however, no definite information regarding this point.

All these facts, except the last, go to show that the outer portion of the globe is much less permeable to water than has often been assumed, and that, in many places at least, the downward percolation is a negligible factor. The groundwater which is met at small though variable depths, and which fills abandoned mine-workings, is held there by the tight rocks beneath it, and is not to be considered the upper part of a mass of water reaching down to 10,000 ft., or any such depth, in the interior. On the contrary, something like 2000 ft. appears to be its limit, and in some regions it ceases at 500 ft.

The explanation lies, no doubt, in the plugging of fissures and crevices with attrition or residual clay, and in the feebleness or disappearance of capillary attraction with increase of pressure. The efficiency of a very thin seam of clay in keeping back water is well known to all miners who have been engaged in wet ground. A layer a quarter-inch thick is water-tight, and often every precaution, as remarked by Dr. Raymond at the present meeting, is taken by the miners not to break through even this small thickness. As to the efficiency of capillary attraction with increase of pressure, I learn from Prof. R. S. Woodward, as I have already said, that our knowledge is

---

* Wm. Hallock, *Proc. Amer. Assoc. Adv. Sci.*, xl., 257, 1891; *School of Mines Quarterly*, xviii., 148, 1897. The latter gives details of the Pittsburgh well also. The section of the well at Wheeling will be found in *West Va. Geological Survey*, vol. i., p. 364, 1899. Professor Hallock states that the well was plugged with an oak plug after his measurements; two years later, when the plug was removed, the hole was full of water, which all believed leaked in at the end of the casing.

very limited, and he at least would hesitate to affirm that it operates. It has been shown, moreover, as I am informed by Dr. A. A. Julien, that when, in testing the absorption of building-stones, pieces are merely soaked in water, the penetration of the water is insignificant; but if the air in the stone is exhausted under an air-pump, or by boiling, or if the block of stone rests on wet felt, then absorption takes place.

The extraordinary impenetrability of some rocks is emphatically shown by the storage of petroleum and natural gas. Both of these, but more especially the former, are wanderers to a remarkable degree, yet they are confined in the ground under very great pressure and are unable to escape. Edward Orton, Sr., satisfactorily demonstrated in 1889 that the pressure of the gas in the comparatively shallow wells of Ohio (1000 ft.) was hydrostatic and due to the groundwater. Nearly all geologists believed the same agent to be the universal cause of the rock-pressure of natural gas; but when the deep gas-wells of New York were drilled from 2250 to 2600 ft., to the Trenton limestone, it was found that some other factor must enter, because the pressure is too great for a hydrostatic cause. Prof. Orton, therefore, and others with him, have abandoned this view.*

In some deep mines water has been encountered in uprising springs, and the same is true of not a few shallow shafts; but I do not think that any springs at less than 1500 or 2000 ft. depth have a bearing on this question. Posepny† mentions one in the Einigkeit shaft, Joachimsthal, Bohemia, that was met at 533 meters (1774 ft.); but in the next paragraph we learn that the uprising waters at Joachimsthal were tapped along the contacts of the veins with basaltic rocks of comparatively late origin, and therefore in a situation involving expiring vulcanism. I do not cite this and the subsequent cases with a view of necessarily referring the waters to exhalations from fused and consolidating or consolidated magmas, but I do mean to use them, along with other considerations, to show the impotence of purely gravitative motive power.

The Comstock lode is the most famous case of a deep, wet mine. Church, King and Becker have all discussed the waters

---

* *Bull. Geol. Soc. Amer.*, ix., 95–99.

† *Trans.*, xxiii., 223.

in their several monographs. Water was tapped on the 2200-ft. level of the Savage, and rose both in it and in the Hale and Norcross to the 1750-ft. level; but there it stopped.

Mr. Becker says that two kinds of water have been met in the lode. One is pent up in confined bodies. It was the tapping of such a body that let the water into the Savage and Hale and Norcross, as just observed. In another case, a cross-cut from the Palmer shaft was invaded by a body of water that rose 100 ft.* and had a temperature of 104° F. The other kind of water rises from the depths. No one doubts that the high temperature of these waters is due to expiring vulcanism, and the focus of the heat is placed by Mr. Becker at not less than two, and more probably four miles in depth.† The region is arid, and it is believed that the water must have come from a distance. A source for it in the Sierras, 12 or 14 miles to the west, is tentatively suggested by Mr. Becker; but there is good reason for thinking some of it, at least, to be a contribution from the eruptives themselves.

Emmons‡ has recorded a very interesting case of an uprising spring in the Geyser mine at Silver Cliff, Colo. The shaft was sunk so that it cut at 2000 ft. the contact between overlying porous rhyolite tuff and the underlying granite. Water in small amount and charged with carbonic acid, and different in composition from the descending waters, which had ceased far above, bubbled into the workings along small fissures parallel with the contact. Here, again, the spring is in a region of vulcanism of rather recent date, geologically speaking, and it is impossible to assert that an abnormal rise in the isogeotherms from this cause is not a factor in the circulation, although the water exhibited only the temperature of the drifts themselves.

It is not my purpose to attempt to show that water does not descend into the earth below 2000 ft., for I believe that it does, although not by any means in the amounts which have sometimes been assumed. I wish to make clear that the amount is probably comparatively small; that there are good grounds for believing that it only descends to great depths by relatively large fissures; and that these are exceptional. To the same

---

* *Fortieth Parallel Survey*, iii., 87.

† *U. S. Geol. Sur.*, Monograph III., p. 264.

‡ 17*th Ann. Rep. Dir. U. S. Geol. Survey*, part ii., p. 458.

degree that the meteoric waters are limited to the relatively large fissures, they are unfavorably situated for the solution of sparsely distributed minerals and metals. I hope to establish, further on, that even if they descend in this way, by a trickle here and a little seepage there, they can never be brought again to the surface, so as to form springs, by gravity and the normal rise of temperature alone.

At the same time, I fully recognize that there is ground for a different view, and that a strong case can be made out for the very slow circulation of water at great depths. But even if it be admitted that this is the case; that the waters become charged with ores; and that they have some tendency to pass upward, by reason of the heat acquired through the normal rise of temperature with depth; it remains true that, in again ascending, they meet descending currents or mingle with relatively stationary water; and they become dilute and disseminated and comparatively weak agents, when contrasted with the much superior efficiency which may be locally conferred upon waters by igneous intrusions. While one cannot deny that, by the former type of circulation and in the long course of geological time, something might be accomplished, yet, *a fortiori*, all the results *might* have been brought about, and there is abundant reason to think that they *were* brought about, by the aid of igneous rocks, as I shall endeavor to show subsequently, by proof additional to what has already been said.

The interrupted passage of the waters, when they do descend, has an important bearing upon the hydrostatic head. Whenever, for example, capillary transmission occurs, the previously acquired head is lost, and the emerging water proceeds on its way only under a newly accumulating head. So far, therefore, as capillary transmission may be assumed, ordinary calculations of hydrostatic pressure, based on distances from the surface, are false. In any event, even with the assumption of channels larger than capillaries, we are forced in these calculations to believe in the practically standing body of water, reaching nearly to the surface, to which objections have been already raised.

Artesian Basins.

The experience which has been gained with artesian wells is the chief foundation of much that has been written upon the

circulation of the groundwater; and yet artesian basins furnish one of the strongest arguments for the storage of water comparatively near the surface, and against its descent to great depths. Within the limits of an area thus supplied with underground reservoirs, it is obviously impossible for waters to descend below the impervious stratum which is the cause of the reservoir, and it would follow that the lower lying rocks would be dry, except so far as they are supplied with waters which have migrated in from points on the surface outside the limits of the catchment-area. In many cases this would involve a journey of many miles, possibly more than a hundred.

Artesian basins of themselves permit but slight circulation of the imprisoned waters, and are most unfavorable places for the formation of anything like veins. They represent just so much water cut off from active work, like a convict in a penitentiary. They may occasionally be tapped off, downward or upward, by faults, just as once in a while a convict escapes, and then the waters may become geologically active. If they are invaded, however, by igneous intrusions with the attendant cracking of the overlying rock, the accession of heat or energy may make them again active agents. The standing waters, and, what is practically the same thing, the waters which rest under such pressure that they do not reach the surface and flow off, are considered to be too inefficient to be important in the formation of veins.

In cases like the Wheeling and Pittsburgh wells, in which from 3000 to 4500 ft. of marine sediments are apparently dry, one cannot but wonder what has become of the sea-water which they must have contained when they were deposited. Instead of receiving new supplies, they have apparently been deprived even of the little which they did possess. Undoubtedly the pressure of overlying masses has effected this result, or else the water has become combined in some chemical way in the rock itself, and has been thus locked up.

Hot Springs.

The most suggestive of all geological phenomena in connection with the formation of veins are hot springs; and there is ground for believing that they cannot be explained on any other assumption than that of an abnormal local rise in the

isogeotherms. As Osmond Fisher has shown,* the isogeotherms cannot conceivably be raised except by igneous intrusions or by the mechanical production of heat along faults, or belts of shattering; and the latter do not compare in effectiveness with the former.

If for a moment we analyze the familiar increase of temperature with descent, a truer conception will be gained. As ordinarily stated, and as a fair average, it may be assumed that the temperature increases one degree Centigrade for each thirty meters of descent, which would be about one degree Fahrenheit for each 55 ft. In a region whose mean annual temperature is 50° F. or 10° C. (that of New York is about 51° F.), in order to reach a depth at which the temperature is 100° C. we would be obliged to descend 2700 meters, or not far from 10,000 ft. Now that meteoric waters may flow from the surface as a hot spring, which has derived its abnormal heat from this deep-seated source, they must descend to a depth which is at least a large fraction of 10,000 ft. and then return. The depth is a larger fraction of the 10,000 ft. than the temperature of the spring would of itself indicate, because the uprising waters have traversed cooler rocks and necessarily have received accessions of descending colder waters. One other important factor bearing on this question is, moreover, the irregular and more or less choked conduits which have already been emphasized.

The following argument has been sometimes advanced, and notably by Van Hise,† in supporting the view that hot springs are the result of normal terrestrial circulations, without accessions of heat other than those which would be received through the ordinary increase of temperature with depth. It is argued that, as the descending column of cold water is heavier, and the ascending column of heated water is lighter, therefore a hydrostatic head is afforded. Water expands about 4 per cent. between 0° C. (or, more precisely, 4° C.) and 100° C., and, for illustration, the case is imagined of a descending column at 0° and an ascending one at 100°. This assumption, or any similar one, loses practically all its force if we bear in mind the following important considerations:

---

* *Physics of the Earth's Crust*, pp. 240–241.

† "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 48 (p. 22 of pamphlet edition).

1. That the descending column becomes gradually heated, so that, even if the conduits formed practically a long U-tube, there would be little difference in head.

2. That the descending column may move in part in a capillary way and lose its head.

3. That water under great load or pressure does not expand according to the 4 per cent. rate named. On the contrary, it may be held by the pressure at fixed volume, despite the added heat. If, for example, we roughly assume a column of water, one square inch in cross-section and two feet high (it is really about 2 ft. 3½ in.) as equal to a pressure of a pound to the square inch, in 10,000 ft. we would have a pressure of something near 5000 lbs. or over 2 tons to the square inch; and in the face of this the expansion of water from an added temperature of 100° C. practically becomes a negligible quantity as contributing to hydrostatic head.

4. We must bear in mind also that the standing body of cold groundwater fills the interstices of all rocks near the surface, except those in very arid regions, and exerts a retarding influence on uprising currents.

When these objections are all appreciated, I think we must admit that, except so far as waters are fed from heights into artesian basins and thence tapped again to the surface, perhaps slightly warmed from having gone to comparatively shallow depths, such a theory of hot springs, or even of warm springs, is impossible. Hot springs can only be developed in the presence of an abnormal rise of the isogeotherms, which rise can only be effectively produced by intruded masses of igneous rock. I will even go so far as to say that it is in the highest degree improbable that any waters which have reached depths even approximating 10,000 ft. can ever again reach the surface and yield flowing springs, except through the propulsion of stores of energy contributed by still heated masses of igneous rock. I regard it as extremely improbable that the water of any natural spring, whose flow is due simply to hydrostatic head, has ever reached more than a very limited depth below the point of emergence. These statements are made in the belief that unless underground water ultimately emerges upon the surface, so as to maintain an activity of movement which this condition implies, its efficiency is so slight and its

stagnation so pronounced that it is of small probable importance in connection with vein-formation of any magnitude. Professor Sandberger and those who stand with him are the only logical lateral-secretionists.

Even in areas showing the structure of an artesian basin, and possessing a theoretical head of hundreds of feet, the water sometimes rises to a given level in a well and then stands below the surface. Abnormally heated waters, such as those of South Dakota, described by N. H. Darton,* can only be accounted for by the presence of eruptives, although Mr. Darton seems loath even to mention igneous rocks as a possible explanation. Yet they would appear to be the only reasonable one, and in this region there is ground for inferring their existence.

In passing from laboratory-experiments in hydraulics to the phenomena of the earth, there is grave danger of error unless one proceeds with great caution. It is much the same difficulty that formerly arose in drawing profiles of country with exaggerated, vertical scales. The sense of true perspective was lost. Mr. Rickard's illustrative figure of the hot-water circulations in a household heating-plant,† likewise cited by Professor Van Hise, would give a very false conception unless used with so much allowance as to be destructive of its force. The open pipes in a house, extending but 50 or 100 feet in altitude, and with an intense source of heat in the cellar, are not comparable to conduits of irregular size, often choked, at times capillary, and with 10,000 feet of gradually warming walls before even a temperature of 100° C. is reached.

In brief, therefore, I believe it to be highly improbable that hot springs are ever produced except in regions of expiring vulcanism; but it is, on the other hand, highly probable that hot springs have been the great producers of veins.

The Irregular Distribution of the Groundwater near the Surface.

Recent observations of Emmons and Weed have emphasized the fact that the level of the groundwater is not a regular and sharply marked surface, but is, on the contrary, very irregular and subject to much fluctuation. The presence of oxidized or

---

* *Am. Jour. of Sci.*, March, 1898, p. 161, and especially p. 168.

† *Trans.*, xxiv., 950.

enriched minerals in some places at depths below the ordinary groundwater level has given rise to this inference. It would appear as if waters become charged with metals within the limits of the gossan, and, descending, react on leaner sulphides so as to enrich them, and that they do so even by diffusion through the standing groundwater and below its level. But it also appears as if there were no standing groundwater and no means of preventing quite deep oxidation and enrichment along some belts, which, because of their open character, may allow the waters to go down, turn and rise again as a spring at some lower point; and this, although neighboring ground, impervious in character, may retain the groundwater at a sharply marked and higher definite level. Naturally, in interpreting the phenomena of gossan-minerals apparently carried downward, we must bear in mind the later geological history of the district, because subsidence, together with the choking and elevation of surface-drainage, may raise the groundwater above its old level, and it may be that some of the minerals regarded as enriched (bornite, chalcocite, etc.) have been deposited by uprising currents.

In regions where the rainfall is small, and where the contributions to the groundwater are correspondingly slight, its level may be very far down; or, if the rocks are shattered, standing groundwater may be entirely lacking, and oxidized ores, so far as they can be produced without the aid of much water, may extend to depths indefinitely great. On the other hand, in an arid region galena may actually outcrop. In the Geological Museum of the Columbia School of Mines there is a large specimen, about a cubic foot in volume, that was pried out of the cropping of the Half-Moon vein at Pioche, Nev., by Prof. Geo. W. Maynard. It is galena and quartz, the former only oxidized on the surface.

All of these points are, however, matters of the anatomy or pathology of already-formed veins, and do not touch the fundamental problems of genesis, to which, in fact, they are related much as are bodily disorders and amputations to embryology and growth.

III.—The Distribution of Mining Districts.

When one considers the country at large (leaving iron-ores out of the question), it is evident that districts favorable to

actual mining are very sparsely distributed. Even in regions like the mountainous parts of Colorado and Montana, where we commonly think of mining as being extensively practiced, the productive areas are separated by vast stretches of country without workable and, I think one may say, without notable vein-development. One rides in a train for hours between the camps, and only for minutes in them. Even making due allowance for lack of outcrops, for forests and for veins concealed by the wash, the mining districts must be described as limited areas of intense local vein-formation, which alternate with vast areas of barren ground.

In the mining districts igneous rocks are present, practically without exception. If we assert that the assumed circulations of meteoric waters, which are thought to be universal in the rocks, and to be due to the ordinary and ever-present increment of temperature with depth, are the causes of vein-formation, we encounter grave difficulties in trying to explain this general absence of veins. Dislocations are everywhere present, and we ought to find veins in a similarly great abundance. On the other hand, if we remember the points made regarding the igneous rocks at the outset, we shall have a much more rational explanation both of the presence and of the absence of the veins.

It must be appreciated by all who are adequately familiar with both the literature and the phenomena, or with either, that ore-bearing veins, especially when of large size, are altogether exceptional and rare occurrences, and their causes are local and exceptional in their nature. No one with a correct sense of perspective can possibly be face to face with the huge stopes of ores of comparatively scarce metals, which some of our mines afford, without marveling greatly that they *ever* happened to be produced in the course of Nature; and in dealing with the elusive but irresistibly attractive problems which their genesis affords, one cannot be too appreciative of the local and exceptional nature of the causes which have produced them. One may, therefore, in endeavoring to explain vein-phenomena as a minor corollary to an all-embracing theory of metamorphism, based on the normal circulations of the groundwaters, miss the very kernel of the matter and fall into the same error that von Buch and other disciples of Werner committed, in the early

part of the nineteenth century, in endeavoring to establish for rocks in general a "universal hypothesis."

Résumé.

The thesis of vein-formation, however presented, is necessarily one of greater or less probability, rather than one of demonstration. The following points may be made in favor of igneous rocks.

1. Igneous rocks contain the metals and the elements of the gangue minerals more abundantly than do sedimentary rocks.

2. Igneous rocks are richly provided with vapors which come up with them from great depths. Igneous rocks are enormous reservoirs of energy.

3. Igneous districts, or districts of combined igneous and sedimentary rocks, are almost always the geological formations in which veins occur.

4. The vapors and solutions from intruded igneous rocks are pre-eminently favorable chemical reagents.

5. Observations in deep mines and the data from very deep wells indicate the general absence of free water in the rocks below moderate depths, except in regions of expiring vulcanism. This is a grave objection to the conception of universal groundwater.

6. Capillary attraction is largely an ascensive force and of problematic existence with increasing pressure. Artesian reservoirs of themselves are unfavorable to extended circulation. There is a strange absence of the original content of water in deep-seated sediments. Standing water in abandoned shafts is strong evidence of the impenetrability of rocks.

7. Hot springs are necessarily connected with an abnormal rise of the isogeotherms, and this can only be explained by intruded igneous rocks or by faults and shattering. The latter do not compare with the former as an efficient cause.

8. The distribution of the groundwater is far less uniform than has been supposed. The groundwater may entirely fail in arid regions.

9. The distribution of mining districts can only be satisfactorily explained by the corresponding distribution of igneous rocks, which have been intruded under circumstances favorable to vein-formation. Under any other view veins should be much more common.

In conclusion, I cannot forbear reference to the subject of the classification of ore-deposits. In November, 1892, I published in the *School of Mines Quarterly* a paper on the "Classification of Ore-Deposits, a Review, and a Proposed Scheme Based on Origin." The same has been subsequently printed, with one or two minor modifications, in the "Ore-Deposits of the United States." After a review of all the known schemes up to that time, and an analysis of their special features, a scheme was developed which sought more consistently than had been done up to that time to bring the ore-deposits under well-recognized geological phenomena. Aside from the ores of igneous origin, and the placers of various kinds, this involved a classification of those phenomena which would give rise to cavities, not of themselves necessarily great, but sufficient to furnish a water-way. These are the determining factors in the location of ore-deposits; they admit of the least possible difference of theoretical views or of interpretation, and they are the common ground upon which observers can best meet in harmony. They therefore furnish much the best basis of classification. I do not believe that any other line of attack of this problem furnishes equal advantages. Therefore, while the conceptions of ascending and descending waters cited by Professor Van Hise in closing his essay give new and significant points of view, yet the interpretation of the phenomena in accordance with them is inevitably destined to raise such well-grounded differences of opinion as to make the scheme impracticable for general use.

The Formation of Bonanzas in the Upper Portions of Gold-Veins.

BY T. A. RICKARD, DENVER, COLORADO.

(Richmond Meeting, February, 1901.)

Introductory.

The presentation to the Institute, eight years ago, of the paper of Pošepny on "The Genesis of Ore-Deposits" has borne fruit in much fresh investigation, as is evidenced, for example, by the group of very valuable papers, by distinguished members of the United States Geological Survey, read at the Washing-

ton meeting—discussions of general principles particularly suggestive to those who are engaged in mining.

Pošepny, in the discussion of his famous treatise, said that the present writer seemed to look at every new conception in ore-deposition "from the sole standpoint of its immediate usefulness in mining."* Protesting mildly against "sole" and "immediate," I accept the impeachment. It calls for no defence.

The Development of Recent Theories.

Given the idea of an underground water-circulation as the chief factor in the deposition of ore, the next step in the inquiry as to the genesis of such deposits is the endeavor to determine which particular part of the general water-circulation is responsible for the results. Around this question have centered the controversies of a generation, and to these controversies we owe the gradual clarification of our ideas upon the processes of ore-formation. It is unnecessary to sketch here their progress from Werner to Le Conte, who combated in 1883 the extreme views of the lateral-secretionists, and in 1893 opposed the narrow interpretation of the ascensionist-theory. The generally accepted opinions of to-day are a well-deserved tribute to his philosophic discrimination.

Thanks to Prof. Van Hise and Mr. Slichter, whose work he utilizes, we have now arrived at a comprehensive conception of the underground circulation, which emphasizes the conclusion that sulphide-ores are generally deposited by ascending waters. In estimating the importance of this conclusion, it is to be remembered that, apart from placers and iron-mines, the largest portion, by far, of the ores exploited by the miner are sulphides. Morever, it has been shown that the other, equally essential, parts of the circulation, namely, its lateral and descending portions, particularly the latter, also play their part, to which many "secondary enrichments" are due.

This approach toward an understanding of the processes of secondary enrichment in ore-deposits is an extremely important advance in the application of geology to the exploitation of mines. For such enrichments pre-eminently constitute the ore-masses valuable to man. Chemistry and physics may unite in determining the conditions favorable to the precipitation of gold;

---

* *Trans.*, vol. xxiv., 966.

geology may unravel the intricacies of rock-structure, but it does not come within the province of these sciences to decide whether a gold-vein will prove rich enough for profitable mining. Nature knows no ratio of sixteen to one, or any other standard of monetary value. Therefore, the determination of the particular conditions favorable to the mere occurrence of gold-ores remains but a barren discovery until it includes some suggestion as to the search for the richest portions. To the geologist, material carrying 2 dwts. of gold per ton is as truly an auriferous deposit as if it contained 12 dwts. per ton; but, under existing economic conditions, the miner may regard the former as only fit for macadam, and the latter as potential of fortune.

When the science of ore-deposits, therefore, has predicted with certainty the places where gold can be found, it has fulfilled a conclusive test of a true theory. But this means to the miner no more than the restriction of his search for profitable gold-deposits to those places where there is any gold at all—a restriction which, after all, amounts to little, for the progress of scientific inquiry and practical exploration has rather enlarged than diminished the field of the distribution of this metal. A greater service will be the determination of the conditions which control the formation and distribution of those particular portions of the multitudinous deposits of gold which constitute the secondary enrichments of the geologist and the bonanzas of the miner.

Such a desired consummation seems now to be nearer of attainment. The practical result of the papers of Messrs. Van Hise, Emmons and Weed will be to direct attention to the one line of inquiry most useful to the miner. Unquestionably the theories of secondary enrichment have been largely suggested by the experience of the men whom the geologists have met at the mines; and the invaluable assistance thus given to mining engineers is a pleasant outcome of such an exchange of views.

The Enrichment of Gold-Veins Near the Surface.

A quartz lode carrying gold in association with pyrite is here taken as the type of deposit under discussion. In lodes of this kind, it is a common experience to find bodies of rich oxidized

ores extending to a variable depth from the surface. In this general phenomenon of enrichment two processes must be separately recognized, namely, relative enrichment by a method of natural concentration and positive enrichment by the deposition of additional gold through secondary reactions.

Enrichment by Concentration.

The iron sulphide accompanying the gold is removed by weathering. Weathering is a process of chemical decomposition and mechanical disintegration in which oxidation is aided by the shattering of the rock due to the alternate expansion and contraction of the water present in its pores, seams and cavities. The depth to which these effects extend will depend upon the facilities afforded for the penetration of surface-waters carrying free oxygen; and it will be regulated by the local groundwater-level. The results observed usually cease at the groundwater-level because at that horizon the descending surface-waters become mingled with the larger body of neutralized water, and so lose their free oxygen. When, however, they can find channels permitting a relatively rapid passage, they may not become at once diffused, and may thus continue their oxidizing action even below that level. But the actual lowering of the groundwater-level, by a change of surface altitude or hydrostatic conditions, affords the chief factor in enlarging the scope of such oxidizing action on the part of the surface-waters.

The chemistry of the process is pretty well understood, and need not be discussed here.

In the case of enrichment by concentration, the evidence indicates that the leaching and removal of the pyrite has been affected without shifting the gold, which remains behind in its native state. I have specimens from Idaho and West Australia exhibiting crumbly native sulphur, within the cubic cavities vacated by the pyrite, and in those from West Australia there is also gold in fine crystals which are readily shaken loose. The removal of pyrite; the occurrence of fine particles of gold in the vacant casts produced by this removal, and the formation of a sintery honeycombed mass of iron-stained quartz are familiar aspects of the process of natural concentration.

Weathering, then, by removing the baser and more soluble

constituents of the vein, decreases the weight without diminishing the volume of the ore, which thus becomes so much the richer *per ton*. Iron-stained gossan, rich in gold, is a familiar occurrence in mining, and the frequent discovery of such material has had a far-reaching effect in determining the character of the industry. Apart from the richness of such oxidized ore, its metallurgical docility greatly enhances its value. In comparison with the unaltered and relatively refractory pyritic ores, the oxidized material is not only easier to crush, but also easier to treat by amalgamation, chlorination, etc. Hence the contrast which is occasionally offered between the early successes of the discoverers of a gold-vein and the subsequent troubles of the mining company which buys their property. The gossan of the gold-vein has been the source of a large part of the world's store of the precious metal; and to it we owe the successful beginnings of many districts, which, if they had been compelled to commence operations upon refractory pyritic ore, would have waited long for their active development.

Secondary Enrichments Due to Descending Surface-Waters.

The diagnosis of the general process by which these are formed by descending waters has been stated in clear terms in the contributions of Messrs. Van Hise, Emmons and Weed.

The occurrence of restricted bodies of extraordinarily rich gold-bearing quartz has been a startling feature of gold-mining in all countries. From them fortunes have been made with picturesque suddenness; and by means of them the inexperienced have been led into sanguine expectations, the failure of which has brought disasters not less romantic, though much less welcome to their victims. Such instances have furnished matter for proverbs concerning the uncertainty of mining; but they are soon forgotten. Nevertheless, the uncertain occurrences of rich ore on which they are based present an important feature of the ore-deposits in all gold-mining districts, though they are more particularly characteristic of desert regions, such as the area of the Great Basin, stretching between the Rocky Mountains and the Sierra Nevada, and also those arid parts of Australia which have yielded so much of the wealth of the colonies.

The outcrop of a gold-vein is not always the richest portion. The sintery gossan formed at the immediate surface may be poor in gold, and yet may be succeeded near, or even below, the water-level, by extremely rich masses of half-decomposed pyritic ore. In such cases it would appear that the gold had been leached out of the oxidized portion of the lode, and had migrated in the wake of the iron until precipitated, so as to form the secondary enrichment now under discussion.

In considering the formation of these bonanzas, one of the first problems presented is the question of the mode of occurrence of the gold in the pyritic quartz of the lode. The evidence as yet available indicates that the gold does not exist in chemical combination with the iron sulphide of the pyrite, but usually occurs in minute filaments or crystal aggregates distributed through the substance, and especially along the structural planes, of the pyrite. In my collection I have a handful of fragments of pyrite obtained from the Orphan Boy mine, in Boulder county, Colo. This mine was the beginning and end of a mining excitement which happened, in the spring of 1892, in connection with a locality named Copper Rock. Under a magnifying-glass the specimens exhibit little crystals of gold, which, by the rounding of their edges, appear in places as globules distributed over the facets and in the crevices of the pyrite.

The behavior of such gold-ore under metallurgical treatment also suggests strongly that its usual mode of occurrence is analogous to the above example. When gold-bearing pyrite is treated by cyanidation, the gold may be leached out without deformation of the pyrite or any other change in its appearance except the acquisition by its facets of a pitted surface suggesting cavities left by the removal of a soluble constituent. Moreover, there are many mining districts yielding gold from pyritic veins in which the native metal is rarely seen. The ores of Gilpin county, in Colorado, for example, contain an average of from 10 to 15 per cent. of iron and copper pyrites; and I know from frequent trial that when crushed and washed in a pan, such material, even though very rich, will not yield a "color," that is, a speck of visible metallic gold. Nevertheless, in the stamp-mill these ores yield their gold to amalgamation, indicating by their behavior in this respect that the gold is in a condi-

tion of such freedom as to permit its separation by a crude mechanical process, and its subsequent ready combination with mercury so as to form an amalgam.

The gold which occurs thus in the pyrite of the quartz-vein is soluble in many natural reagents, some of which are formed in the very process of weathering which leaches the pyrite, while others are known to be present in the surface-waters which circulate through the lode-fractures under observation at the present day. By whatever means it is dissolved, the gold is then supposed to be carried by the surface-waters in their descent toward the groundwater-level, where it is precipitated under conditions to be discussed in due course.

Solvents.

In the process of weathering, the pyrite yields many subordinate compounds, such as sulphuretted hydrogen, sulphurous and sulphuric acid, and proto- and sesqui-sulphates of iron. Of the latter, the sesqui-sulphate, $Fe_2(SO_4)_3$, is a solvent for gold, and has been cited by Wurtz and Le Conte in early discussions concerning the origin of masses of native gold in oxidized ores. Dr. Richard Pearce, in later years, has frequently drawn attention to the probability that this sesqui-sulphate is a factor in the process of gold-deposition.*

The gold-deposits in the cavernous quartzite of Battle Mt., Colo.,† have characteristics which appear to confirm this view. In these ores large pieces of native gold, of a nuggety appearance, but really crystalline in structure, have been found associated with horn-silver and the sesqui-sulphate of iron. The latter occurs in lumps, mixed with clay; and although these are very rich in gold, the gold occurs in a form not to be detected by careful panning. Analyses of several large lots of ore showed the presence of 12 per cent. of the hydrated sesqui-sulphate of iron.‡

But other solvents, capable of doing this work, also occur in nature, and, although the amount of any one of them to be detected in existing surface-waters may be minute, we have to re-

* Presidential Address, *Proc. Colo. Sci. Soc.*, vol. iii., part ii. (1889), p. 244.

† F. Guiterman, "Gold Deposits in the Quartzite Formation of Battle Mountain, Colorado," *Proc. Colo. Sci. Soc.*, vol. iii., part iii. (1890), pp. 264–268.

‡ *Ibid.*, p. 266.

member that the processes of nature are permitted so much more time than those of the laboratory that the dilution of the solution is compensated by the quantity of it.

Most writers refer to chlorine as a possible reagent. Such a reference is suggested not only because it is a prominent reagent in the metallurgical practice of to-day, but also by the fact that it has a wide distribution throughout nature in the form of common salt. This is most apparent in arid regions where evaporation causes concentrated solutions to be formed. Thus, in the deserts of West Australia the water encountered in the mines is always brackish, and frequently contains more salt than the sea.* The water of the Great Boulder Proprietary mine, at Kalgoorlie, in 1897, contained 6402 grains of common salt per gallon.† A considerable amount of magnesium chloride was also present. In some of the water used in the stamp-mills, and obtained from temporary "lakes,"‡ the salts were present up to the point of saturation and the liquid carried further salts in suspension, so that the amount reached as high as 30 per cent., rendering the term "brine" more suitable than "water." This liquid contained 17 per cent. of salts in solution even when most diluted by recent rains, and it therefore afforded a parallel to the Dead Sea, the waters of which contain from 20 to 26 per cent. of salts, of which 10 per cent. is common salt. These excessive percentages are not due to the presence of deposits of salt in the rocks of the district, but simply to the concentration brought about by the excessive evaporation§ which takes place in a hot, arid climate.

Mine-waters frequently contain a noteworthy quantity of chlorine, as chloride of sodium. At the Mammoth mine, in Pinal county, Arizona, the water carries five grains of salt per gallon, while the well-water, used in the stamp-mill, situated in the valley below the mine, contains twice as much.|| This would be equivalent to six grains of free chlorine per gallon.

* Sea-water contains $3\frac{1}{2}$ per cent. of salts, three-quarters of which is common salt, the chloride of sodium.

† This is equivalent to 9 per cent.

‡ "Sinks" or salt-marshes. They form an important feature of the physiography of West Australia.

§ The rate of evaporation, in the region mentioned, has been estimated to be as much as 7 ft. per annum.

|| As I am informed by Mr. T. G. Davey.

The larger amount contained in the water from the well, as compared with that in the drainage of the mine, suggests the results of surface-leaching. Even in mountainous districts, such as Cripple Creek, Colo., the mine-waters carry chloride of sodium to a noteworthy extent. The water of the Independence mine contains three grains per gallon.

Another suggestive feature is offered by the abundance of horn-silver or cerargyrite, the chloride of silver, throughout the dry tracts of Arizona, New Mexico and Nevada.* Prof. Penrose emphasizes this interesting fact, and connects it with the bodies of salt water which still survive in places as "sinks" and "lakes."† Furthermore, the oxy-chloride of copper, atacamite (which derives its name from the Atacama desert, between Chili and Peru), is frequent in these regions. Another and more uncommon mineral may also be mentioned in this connection. In the Mammoth mine, already cited, and in the well-known Vulture mine, both in Arizona, the precious metals are associated with vanadinite, which contains chlorine as a chloro-vanadate of lead, $3Pb_3(VO_4)_2; PbCl_2$.‡ Thus the chlorides of copper, lead and silver are found in the oxidized ores of these regions, while the corresponding combination of gold is absent. The explanation is obvious. The chloride of gold is an unstable and readily soluble compound, while the minerals formed by the corresponding combination with the baser metals are comparatively insoluble in water, especially the chloride of silver, for the abundance of which there is therefore a good reason. It remains but to add that, in several Arizona mines which I have sampled, the ores above the water-level carried a notable proportion of silver with very little gold, while in depth the silver contents have diminished and the gold has increased, especially in the vicinity of the water-level.§

Of the many reagents which would liberate the chlorine from salt, it is only necessary to mention ferric sulphate and

* The general occurrence of horn-silver in the outcrops of lodes throughout the southern parts of Arizona and New Mexico has originated the term "chloriding" which the miners employ as a synonym for "prospecting," which, by the way, the Australian calls "fossicking."

† R. A. F. Penrose, Jr., "The Superficial Alteration of Ore-Deposits," *The Journal of Geology*, vol. ii., p. 288, 1894.

‡ Dana.

§ I may instance two well-known mines, the Mammoth and the Commonwealth.

sulphuric acid, both derived from the ordinary oxidation of pyrite. The hydrochloric acid thus formed would yield free chlorine in the presence of manganese oxides,* which are very prevalent in the upper portion of gold-lodes, in the form of the black earthy mineral, psilomelane.

There are other possible solvents which need not be discussed here.

Precipitants.

Whatever the solvents which leach out the gold from the superficial portions of the vein, there is assuredly no lack of precipitants. It is probable that the gold does not migrate far before encountering conditions which compel deposition. Even when it is eventually carried to a considerable distance it is most likely that such removal is effected by alternating stages of precipitation and solution.

Organic matter is a probable precipitant for the gold in such surface-waters. It exists deeper than hasty observation would suggest. At the Great Boulder Main Reef mine, at Kalgoorlie, I saw the roots of trees which, in their energetic search for moisture, had attained a depth of 85 ft. below the surface; and at the Sugar Loaf mine, near Kunanalling (also in West Australia), I saw a similar occurrence at a depth of 74 ft.†

Another agency which, under certain chemical conditions, is a probable factor in reducing the gold from surface-waters, is pyrite itself. Thus, the gold dissolved from the decomposed pyrite at the surface may be precipitated upon the unoxidized pyrite deeper down. Among the exhibits belonging to the Colorado Scientific Society is a bottle containing cubes of pyrite, on the faces of which crystals of gold are to be seen. They are the result of one of Dr. Pearce's experiments. The gold of a Cripple Creek ore was dissolved by using common salt, sulphuric acid and psilomelane as reagents, the chlorine being

---

* See the experiments made by Dr. Don, to test this matter, *Trans.*, xxvii., p. 599.

† Since writing the above I have read Professor Vogt's very valuable contribution, and I note that he mentions having seen, among the mineral exhibits at Paris, specimens of such roots, from the Great Boulder Main Reef mine, on which gold had actually been precipitated. "Problems in the Geology of Ore-Deposits," *ante*, page 167.

thus obtained in a manner analogous to conditions which probably occur in nature. This solution was placed in a small bottle, and to it were added a few large pure crystals of pyrite from the St. Louis mine, at Leadville. After several months the gold became precipitated in the manner described. In this connection the story of Daintree's experiment, which I have quoted before,* is worth repeating. In 1871, Daintree commenced a series of experiments at Dr. Percy's laboratory at the Royal School of Mines, London. In a number of small bottles he placed a solution of chloride of gold, and to each he added a crystal of one of the common metallic sulphides, such as pyrite, blende, galena, etc. At the time when Daintree died, a few years later, no results could be discerned; but one of the bottles, containing the gold solution and a crystal of common pyrite, was removed to Dr. Percy's private laboratory, in Gloucester Crescent, and there, in 1886, the experiment was completed by the discovery of a cluster of minute crystals of gold upon the smooth surface of the pyrite. The experiment had occupied fifteen years; and on account of its very length it may be said to have more nearly approached the actual conditions occurring in nature.

In a case like that of the "Indicator," at Ballarat, which I have lately described again,† it may be questioned whether it is the pyrite in the thin seam of graphitic slate or the carbonaceous matter of the latter which causes the precipitation of the gold. Even if the pyrite was the decisive factor, it must be remembered that it, in turn, probably owed its previous deposition to the action of the carbonaceous precipitant in the Indicator seam. This would apply also to the beds of black slate which have had so marked an influence on the occurrence of gold in the Gympie district,‡ Queensland, but it would not, I think, be applicable to the Rico deposits,§ where pyrite is not an especial constituent of the black shales, as compared with the sandstone beds of the same stratified series.

---

* *Trans.*, xxii., 313.

† "The Indicator Vein, Ballarat, Australia," *Trans.*, xxx., 1004.

‡ J. R. Don, "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 577–580.

§ "The Enterprise Mine, Rico, Colorado," *Trans.*, xxvi., 906.

Solution and Precipitation.

It is to be noted tha in the two examples of ore-forming processes which have been considered, the gold in the superficial part of the vein is supposed, in one case, to remain in the gossan after the pyrite has been removed, while in the other instance the gold also is dissolved and carried elsewhere. This may appear contradictory. It is a good illustration of the perplexities arising from the application of chemical hypotheses to the theory of ore-deposition.

Nature knows no interval of inaction; solution is going on at one time, precipitation at another. The gold is constantly the object of one or the other activity. After the pyrite is removed, or while it is still undergoing leaching, the gold is being dissolved, but more slowly than the baser metals. That which remains to enrich the gossan may well be supposed to be the survival from a larger quantity of gold which has been undergoing slow solution. The gold which was deposited deeper down, from the surface-waters, may, as erosion takes away the upper part of the vein, eventually find itself close to the surface and undergo re-solution. It is a question whether the mining of to-day breaks in upon the gold-deposits at one stage or another of a continuous process. The miner finds the balance of gold left on deposit from a current account in Nature's bank. Solution and precipitation are everywhere in action; it is the excess of one or the other which determines the formation of ores.

The Distribution of Ore-Bonanzas.

The shifting of the zone of oxidation is a principal factor in determining the distribution of rich ores. By the erosion of the superficial portions of the vein, in common with the enclosing rock, the further downward penetration of the oxidizing agencies is facilitated. The depression of the groundwater-level lowers the zone at which precipitation of gold, from descending surface-waters, takes place, while, on the other hand, when a change in the hydrostatic level causes the groundwater to rise, the zone of deposition moves up. In both cases the tendency is to give vertical extension to the rich mass of secondary gold-ore, and thus to produce the occurrence which miners term a "shoot."

Erosion is followed by another result, in itself of great importance to gold-mining. The steady removal of the superficial part of the vein causes the lower portion, which has been enriched at or below the groundwater-level, to undergo a relative elevation by being brought nearer to the surface. In this way the bonanza-zone, in process of time, may become the outcrop. This appears to me to explain the occurrence of the extraordinarily rich bunches of specimen-quartz, such as made West Australia famous in 1894 and 1895, and started the mining stampedes of other days elsewhere. In many instances fortunes have been gathered almost at the grass-roots from veins which, on systematic development, have proved unprofitable. The gold-quartz veins of West Australia traverse rocks of great geological antiquity which have not, during late geological periods, undergone any notable disturbance. We do not know at what period the veins were formed; but, even though their formation dates no further back than the beginning of the Tertiary, they have since been continuously exposed to the same quiet forces of erosion which have leveled the region until it appears as an arid table-land strewn with the wreckage of geological time.

Whatever the alternations of slow depression and elevation which have affected this region, as part of a continental area, it is certain that erosion has been long at work with patient constancy. Throughout this period chemical agencies have been active in the zone of weathering, near the surface, removing the gold to the zone of precipitation, near the groundwater. Whatever the slight changes which have marked the level of the groundwater from time to time, erosion has continued uninterruptedly, and therefore it has steadily gained, with the result that the enriched portion of the vein has been brought nearer and nearer to the actual surface, until it finally appears as the outcrop which rewards the search of the prospector.

The Localization of Ore-Shoots.

To the miner the localization of these richer portions of the vein is of more immediate practical interest than the theory of their origin. A gold-vein is not a homogeneous mass of auriferous quartz, of tabular form, penetrating the rocks like a sheet of paper, but rather as an irregular occurrence of ore, the

composition and shape of which are very variable, because they are the result of chemical agencies and structural conditions of great complexity. While the traces of the agencies which precipitated the ore are obscure, because they have been largely obliterated by subsequent chemical action, the relation between the vein and its encasing rock can often be traced by observation. In this direction the miner obtains great aid from the geologist. The transactions of this Institute and the publications of the U. S. Geological Survey contain numerous clear expositions of such structural relations. The monographs on the Leadville and Eureka mining districts may be especially instanced as affording striking examples of the direct application of geology to underground work.

Australia.—One of the best examples of the localization of rich ore came under my notice in 1890 in the Bright mining district. Bright is geographically in the Australian Alps, and geologically in the Upper Silurian slates and sandstones. Though these rocks have undergone metamorphism, and exhibit a well-developed cleavage, yet their bedding has not been obliterated. The veins cross the bedding-planes of the enclosing country both in strike and dip. When investigating the distribution of the ore in the mines of this district, I found that the ore-shoots had a pitch corresponding with the line of intersection between vein and country. This was well illustrated at the Shouldn't Wonder mine, 7 miles from the town of Bright. The lode was a simple quartz vein from 15 to 24 in. wide, carrying a small percentage of pyrite. It had a strike of N. 28° W. and a dip to the NE. of about 75°, while the country dipped SW. 79° and had a strike of N. 55° W. The plane of the vein cut across the beds of the country and the intersections thus produced were to be seen along the foot-wall of the lode as lines, pitching 42° to 46° southward. While the foot-wall was more regular than the hanging, and therefore exhibited this feature best, yet the hanging also carried lines corresponding with those observed on the opposite wall.

The boundaries of the ore-shoots in the mine followed these lines; and the longitudinal section of the workings, as seen on the mine-maps, proved also that these lines of intersection had an inclination which coincided with the trend of the ore-bodies, as stoped out between the four successive upper levels of the property.

At the Myrtle mine, in the same district, there was the same correlation between the pitch of the ore-bodies and the line of intersection of the wall of the lode with the bedding-planes of the enclosing country. The stratification was distinct, the rocks consisting of altered, silicified slates of a gray to gray-blue tint. In the stopes above the 700-ft. level the pay-ore was separated from the normal valueless quartz of the lode by a small step, due to the irregular fracture of the vein in crossing two beds of unequal hardness. It marked the line of intersection between lode-plane and country bedding, and also proved to be the boundary of the pay-shoot. In the different portions of the mine the variation in the dip of the country produced variations in the angle of the lines of intersection, and also in the pitch of the ore-shoots.

It is not often that the formation traversed by a vein has such a simple structure as was presented by these Silurian sedimentary rocks; but it is probable that in other districts also the pitch of the ore-bodies may have been determined by structural conditions of a similar kind, which have been obscured, however, by metamorphism.

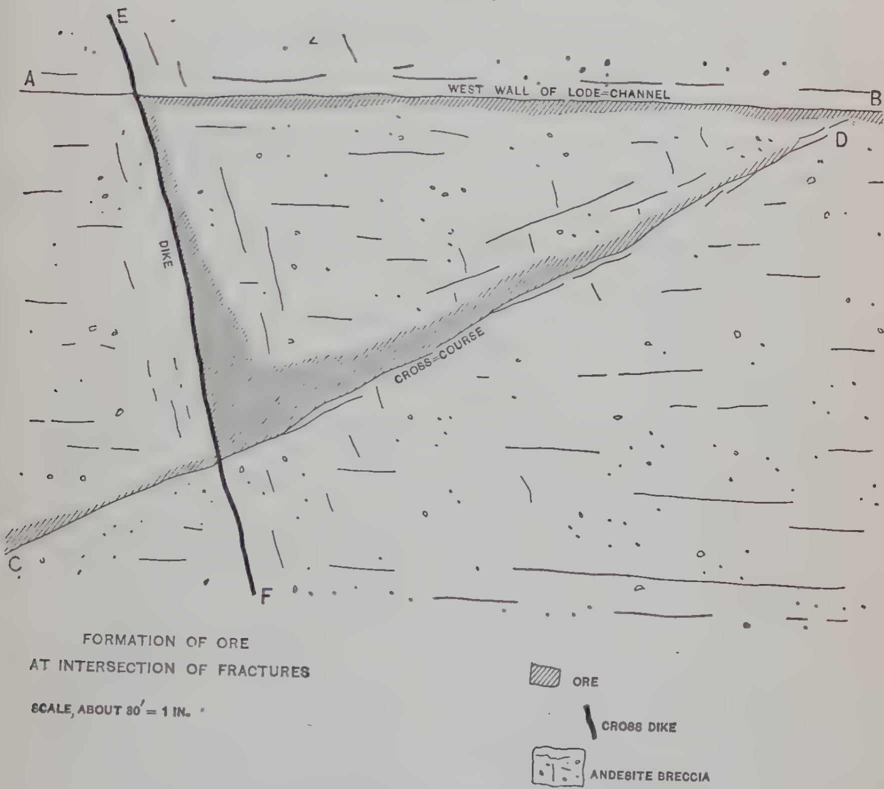
Colorado.—Experience has shown that the intersection of fractures favors the occurrence of rich ore-bodies. An interesting example was afforded by the Moon-Anchor mine, at Cripple Creek, in 1899. This is illustrated in Fig. 1. The ore in the mine occurs in a lode-channel marked by a band of fractured andesite breccia. At the 400-ft. level a small dike (EF) of granite, 2 to 6 in. thick, intersects the lode-channel at a place where a counter-fracture (CD) also traverses it. A triangle is produced by these intersections, and the ore is proved to surround a block of ground which is also mineralized, but not sufficiently so to be regarded in its entirety as pay-ore. At the crossing of the dike and cross-fractures a very rich body of telluride-ore was encountered.

This reminds me of the Yankee Girl ore-body, mentioned by Emmons.* This body of ore was of phenomenal richness, many ten-ton lots being shipped which carried 7 or 8 ounces of gold and 3000 to 4000 ounces of silver per ton. The ore was also rendered remarkable by carrying the rare mineral stro-

* "The Secondary Enrichment of Ore-Deposits," *Trans.*, xxx., p. 196.

meyerite, a sulphide of silver and copper, Mr. Emmons speaks of the bonanza turning into low-grade pyritic ore as depth was attained. I may add* that this change was not gradual, but sudden, and coincident with certain structural relations. At the surface, the vein consisted of comparatively low-grade ore, which led to the finding of a nearly vertical "chimney," aver-

FIG. 1.



MOON ANCHOR MINE, CRIPPLE CREEK.

aging only 25 to 30 ft. in diam., of extraordinarily rich ore, consisting of the copper sulphides, bornite and erubescite, with stromeyerite and barite. The gold in the ore was associated with the barite. From the second to the sixth level, at about 500 ft. below the surface, this bonanza proved immensely productive; then, suddenly, a flat floor, dipping W. and accompanied by clay, crossed the deposit. This flat vein was worked for 90

* From notes made during an examination of the mine in January, 1892.

ft., from the south drift at the No. 6 level, and contained ore similar to that of the Yankee Girl chimney. The latter was found again deeper down, and out of its former line of descent, but it was much diminished in richness, and appeared to merge into the general body of low-grade copper and iron pyrites* which characterized the lode at the tenth level. This mine and its neighbors, the Robinson and Guston, are idle now. They are in the andesite breccia of the San Juan region. The Yankee Girl chimney was situated, I believe, at the crossing of three lode-fractures, appearing as breaks in the andesite, which was bleached and mineralized where they traversed it. It was a curious feature of this mine, and of the Guston also, that the short, very rich bonanzas of the upper levels gradually lost their definition, that is to say, they became no richer than the intervening portions of the lode. This was interpreted as a "lengthening" of the ore-shoots, which may be true, viewed in one way; but I think that it should be more properly regarded as an impoverishment of the lode, marked by a disappearance of the bonanzas. The surface-waters of these mines are very acid, as Mr. Emmons remarks. At the Yankee Girl mine it became necessary to encase the pipes in redwood, brought from California. I found that the water issuing from a shallow adit (73 ft. below the collar of the shaft) readily precipitated copper on scrap iron. Ore-forming agencies were evidently still at work.

California.—In California, especially in that mining region which follows the foothills of the Sierra Nevada and traverses the counties of Amador, Calaveras and Tuolumne, the occurrence of pockets of rich ore, full of native gold, is a notable feature of the superficial parts of the quartz-veins. These pockets appear to be confined to the zone between the surface and the water-level, and to be dependent upon the results produced by the small cross-veins which encounter the main lodes. In 1887 I had the pleasure of extracting, in two hours, a little over 170 ounces of gold, worth about $3000, from one of these pockets. It was at the Rathgeb mine, near San Andreas, in Calaveras county. The main lode consisted of 5 to 8 ft. of massive "hungry-looking" quartz, the foot-wall of which was a beautiful augite-schist and the hanging a hard diabase. The water-level was 160 ft. below the surface. Down to this

* Assaying 20 to 60 ozs. silver, 1 to 4 dwts. gold, 5 to 15 per cent. copper.

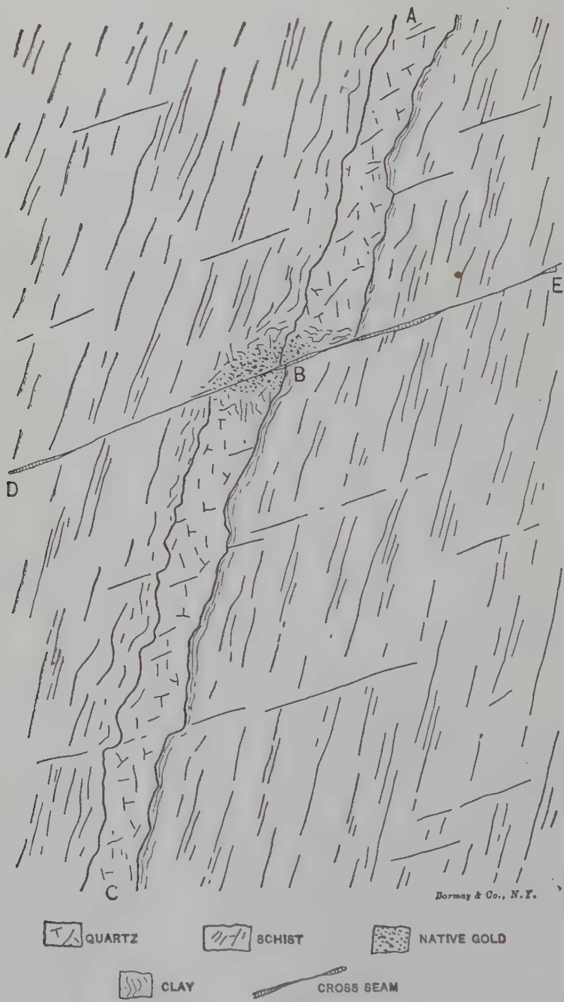
point, the country was oxidized, the hanging-wall exhibiting only slight alteration, while the schist of the foot-wall was softened and decomposed almost to a clay. This was traversed by numerous small veins, which appeared to act as "feeders," forming bunches of rich ore where they encountered the main lode. At the 120-ft. level, south from the shaft, there were some old workings; and the examination of these led to the discovery of a small seam, about one-sixteenth of an inch thick, filled with red clay which carried a good deal of native gold, as was proved by washing it in a pan. An experienced miner was put to work, with instructions to follow this small streak. It varied in thickness, and occasionally opened out into small lenticular cavities, containing a clay in which the gold was distributed like the raisins in a pudding. Each of these "pockets" yielded several hundred dollars' worth of gold. At length the streak widened to 6 or 8 inches of quartz, lined with clay. The amount of red clay commenced to increase; coarse gold became more frequent; and a big discovery was hourly expected. It was finally made. The vein suddenly became faulted, and at the place of faulting there was a soft, spongy, wiry mass of gold and clay—more gold than clay. The first handful I broke, while yet the stope was thick with powder-smoke, contained three ounces of gold. Within the next two hours this pocket gave us $3000, and during the following week it yielded over $20,000, an amount which was obtained at a total cost of less than $200. When it had been worked out, it was easy to observe the conditions which determined its occurrence at this place, as Fig. 2 will explain. The vein, AC, had been faulted about its own width, namely, 10 inches, by a small cross-seam, DE, and at this intersection, B, the pocket lay. The gold was spongy and was intermixed with quartz. The clay which penetrated the whole mass was partly red and ochreous, and partly a gray gelatinous material. In the quartz, and associated with the gold, there were acicular black crystals of pitch-blende (uraninite), together with uranium ochre. This association of gold with uranium is uncommon.

New Zealand.—Intersections which coincide with enrichments form a notable characteristic of the Hauraki gold-field* in the north island of New Zealand. In this district the occurrence

* It is also known as the Thames district.

of patches of native gold is an important feature of the regular mining operations. When I was there, in 1891, each stamp-mill had its "specimen-stamp," a single stamp working in a

FIG. 2.



OCCURRENCE OF A 'POCKET.'

separate mortar, and employed solely for the treatment of specimen-ore. These rich patches occur at the places where the "reefs" or lodes cross bands of flinty quartz. The latter are known among the miners as "flinties." They vary in thick-

ness from a few inches to mere threads of chalcedonic quartz. They are barren in themselves, but have a favorable effect on the gold-veins. The latter are also intersected by cross-veins, producing an enrichment similar to that caused by the "flinties." Fig. 3 is a sketch of one of these intersections, as seen by me in the Moanataeri mine. The lode, AB, consists of a series of small seams of quartz, conforming to the struc-

Fig. 3.

ENRICHMENT AT INTERSECTION MOANATAERI MINE, NEW ZEALAND.

tural lines of the enclosing country, which is hornblende-andesite. The cross-vein, CD, is a band of soft gray decomposed rock, which also carries a number of small quartz-seams, but only near its crossing with the main lode, AB. The line of CD is parallel to a large fault, to be seen elsewhere in the mine-workings. The "leaders," or quartz-seams, in AB are gold-bearing, and exhibit marked enrichment at the intersection with CD.

The prevailing formation of this mining district is an andesite, which is traversed by soft bands of decomposition, called "sandstone" by the miners. The latter, when penetrated by quartz-seams, are favorable to the finding of ore. The gold-occurrence is essentially sporadic and dependent upon local enrichments, such as have been described. The district is surrounded by thermal springs, and is near the well-known volcanic region of Tarawera, which was active in 1884. The mine-waters are heavily mineralized and very acid, so that the metal screens used in the mills are quickly corroded. Tellurides and selenides of gold have been detected in the ores; but the precious metal is usually found native and in coarse particles, which are frequently coated with native arsenic. The district is one which, I think, if thoroughly examined, would afford many suggestions regarding ore-deposition.*

Concluding Remarks.

It is to be hoped that the recent recognition of the agencies which bring about the formation of enrichments by surface-waters will not cause too violent a swing in the direction of a sweeping advocacy of the general efficiency of descending solutions to form ore-bodies. The study of the problems of ore-occurrence has been hindered in the past by such reactions from one extreme view to its opposite. Therefore, in concluding this contribution to the discussion of the results produced by descending surface-waters, I would emphasize the wider agency of ascending solutions in forming the ore-masses amid which such secondary enrichments are occasionally found. It is agreed that the sulphide-ores are primarily deposited from ascending waters; it is also likely that such a result is repeated. A region once subjected to fracturing, which has permitted the subsequent passage of mineral-bearing solutions, is likely, at a later period, to be subjected to a repetition of these activities. The geological history of many mining regions gives clear evidence of a repeated disturbance of structure. This is

* The best description which has come under my notice is "The Geology of the Thames Goldfield," by James Park, read before the Auckland Institute, 1894.

See also "On the Rocks of the Hauraki Goldfields," by F. W. Hutton, *Proc. Austral. Assn. Adv. Sci.*, 1888; and J. R. Don, "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 584–589.

indicated by the existence of several systems of fractures crossing each other, the later ones dislocating the earlier. It is probable that each period was marked by mineralization, the character of which may have varied. The banded arrangement of the lodes of certain districts, such as Freiberg, Rico and Butte, suggests this. Enrichment may have been caused by mere addition; the introduction of other metals may have changed the average composition of the ore in the lode so that it is now extremely valuable, whereas before it may have had no economic importance; a silver-ingredient may have been added to the gold-contents, or the addition of copper may have made a deposit doubly valuable by improving its metallurgical character. I hope the present discussion on ore-deposition will prove as inspiring to further investigation as did Pošepny's paper of 1893, and that data concerning the possible secondary enrichment of sulphide-ores by the repetition of ascending solutions will be sought for. There is nothing like a working theory to sharpen the observation. Theories do not alter facts, but they often lead us to find new ones.

In cordially welcoming the splendid treatise of Professor Van Hise I need make no reservation. When Pošepny made clear the essential character of the upper or "vadose" water-circulation, he did us a great service; and when he combated "lateral secretion" he overthrew a very narrow interpretation of ore-formation, which was calculated to hinder seriously our progress toward the understanding of these difficult problems. But Pošepny was carried so far by his controversy with Sandberger as to over-emphasize the sole agency of ascending currents. At that time, in 1893, I demurred to this extreme view and said, "the word circulation is the key to the whole matter."* By this I meant that the entire underground water-circulation played a part in the formation of ore, and that to swing from one portion of that circulation to another, restricting oneself to the agency of either, would not (so it seemed to me from experience in the mines) solve the problem.

It does not appear to me that Professor Van Hise has erred by exaggerating any particular view of the subject. His elucidation of the water-circulation as a complete system is based on a

* *Trans.*, xxiv., 950.

broad conception of the whole matter. Of course, in indicating the work done by an agency hitherto largely overlooked, he was compelled to place some emphasis on certain neglected features of the descending portion of the water-circulation, and thus to give it some prominence in his masterly analysis. This makes the consideration of the question of secondary enrichments by surface-waters one of the most valuable parts of his treatise.

Regarding this question of secondary enrichment, it is to be pointed out that all ore-deposits are "secondary," the ore as found by the miner being merely the last term of a series of solutions and precipitations through which its substance has passed in a constant shifting due to the underground water-circulation. However, the last stage of the journey is the only one of immediate importance to the miner; and the determination of the causes which brought it there is, to him, far the most interesting aspect of the general inquiry. That Mr. Emmons should also have investigated and illuminated the problem is matter of much pleasure to a great many, engaged in mining throughout the West, to whom his geological contributions have seemed to possess a practical bearing and value unfortunately not always found in scientific descriptions of geological phenomena.

The Caliche of Southern Arizona: An Example of Deposition by the Vadose Circulation.

BY WILLIAM P. BLAKE, F.G.S.,

Director Arizona School of Mines, Tucson, Ariz.

(Richmond Meeting, February, 1901.)

In southern Arizona and in Mexico the word *caliche* is in general use to denote a calcareous formation of considerable thickness and volume found a few inches, or a few feet, beneath the surface-soil, upon the broad, dry, gravelly plains and mesas.

In western South America the same name is applied to the beds of crude soda-niter (Chili saltpeter). While these deposits of South America and of Arizona are totally different in composition, and have nothing in common, except that both occur in

layers in the strata near the surface, it is probable that an explanation of the origin of the calcareous beds may equally apply to the accumulation of soda-niter and other deposits of easily soluble minerals. But the name, taken from the Latin, *Calx*, is more appropriate to the calcareous beds than to those of niter.

Caliche has a wide distribution in the arid regions of Arizona and Mexico. It is usually hidden from view by a slight covering of soil; but it is easily found by digging, and is often revealed by a flow of water during heavy rains. It is practically a continuous sheet, from three to fifteen feet thick, of earthy limestone or travertine, through which the smaller plant-roots find their way with difficulty. The presence of this comparatively impervious layer of cemented earth may account for the absence of trees, or of the larger shrubs, over wide areas. The shrubs which gain a foothold are those whose roots do not extend far downwards, and which do not require much water, such as *Larrea Mexicana* and the *Cactaceæ*. If trees are planted, it is necessary to break up the *caliche* by blasting, or at least to crack the upper layers. The top of the *caliche* is more dense and solid than the lower portions. The surface of this top crust, or layer, is comparatively smooth, though undulating, while the lower portions, under the crust, are irregular, cavernous, earthy and very porous, blending gradually with the materials of the sandy and gravelly beds, from which they are divided by no sharply defined plane of stratification or separation. The *caliche* invests, surrounds and includes sand-grains, gravel, and more or less earthy material, but seems to have had the power, especially in its upper crust, of extruding the coarse materials of the soil to a great extent.

The deposit does not form a regular horizontal bed conformable with the rude stratification of the gravels and sands, but conforms roughly with the general surface, rising and falling with the undulations of the mesa. There are, in places, repetitions of the compact layers, separated by a few inches of the amorphous and more earthy deposit.

In cross-fracture, this upper crust of the *caliche* exhibits distinct, fine lines of successive layers, in thin sheets, along which the rock splits with some ease, while there is a rude columnar fibrous structure transverse to these layers, sometimes in diver-

gent lines from below upward.* Close observation detects in some places small perforations, like pin-holes at the top, which enlarge gradually below and penetrate the entire compact crust, becoming lost in the irregular amorphous granular mass. These holes are often occupied by rootlets of plants; but this is not regarded as evidence of any connection between the deposition of the *caliche* and plant-life—a cause of deposition to which great importance is attached by some authorities.† The *caliche* is an example of deposition independently of the influence of organic agencies.

In chemical composition the *caliche* is essentially a lime carbonate, but contains some calcium, magnesium and aluminum silicates, as more fully shown by the result of an analysis made by my assistant, Mr. J. S. Mann, in the laboratory of the Arizona School of Mines:

Calcium carbonate ($CaCO_3$),	78.28
Magnesium carbonate ($MgCO_3$),	2.13
Calcium silicate ($CaSiO_3$),	5.57
Aluminum silicate (Al_2SiO_5),	7.37
Ferric oxide (Fe_2O_3),	1.88
Moisture (H_2O),	1.20
	96.43

This *caliche*, unlike the deposits of travertine formed in the open air, is not sufficiently compact and solid to be useful in construction, as was the travertine of ancient Rome. When calcined, it yields good caustic lime, which, tempered with sand, makes a strong, quick-setting mortar or cement. It is quarried and used for this purpose in some places. Occurring, as it does, in mixture with gravel and sand, it has the appear-

* "Sorby has shown that in the calcareous deposits from fresh water there is a constant tendency towards the production of calcite crystals with the principal axis perpendicular to the surface of deposit. When that surface is curved, there is a radiation or convergence of the fibre-like crystals, well seen in sections of stalactites and of some calcareous tufas." Cited by Geikie, *Text-Book Geology*, 3d Edit., p. 150.

† Dana, for example, citing from W. H Weed, says: "Some of the travertine deposits of Gardiners River and elsewhere are a result of the growth and secretions of conferva-like plants." (*Geology*, 4th Edit., p. 133.) Geikie says: "But besides giving rise to new formations by the mere accumulation of their remains, plants do so also both directly and indirectly by originating or precipitating chemical solutions," etc. . . . "Some observers have even maintained that this is the normal mode of production of calc-sinter in large masses, like those of Tivoli." (*Geology*, 3d Edit., p. 482.)

ance of an artificial mixture, and as such was once supposed to have been laid down as a foundation by the builders of the Casa Grande in Arizona. On the line of the Phœnix and Prescott railway, it has been found that railway ties last longer when laid in the *caliche* then in ordinary soil. Analysis of this *caliche* showed that it did not differ essentially from the *caliche* of other places.

The great plain or mesa of Tucson affords one of the best examples of the occurrence of the *caliche*. This mesa, which appears like a great plain, is in reality a combination of gentle slopes from the surrounding mountains. The area within which the phenomena of the *caliche* are shown is probably not less than 400 square miles, and lies between the Santa Catalina Mts. on the north, the Rincon and Rillito mountains and the Santa Rita ranges on the east, and the Tucson Mts. on the west. Toward the south and northwest the country is open in the direction of the valley of the Santa Cruz. The Santa Cruz and the Rillito are the visible channels of drainage; but there is, in addition, an extensive underground flow of water as widely spread, possibly, as the area mentioned, but probably strongest in volume under and near the river channels draining to the northwest. The general altitude of the mesa above the sea is from 2400 ft. at Tucson to 3000 or 3400 ft. about 20 miles eastward. These declining slopes are formed, for the greater part, of the *débris* of the surrounding granitic and gneissic mountains—the "wash" or gravel and sand which has been washed out from the cañons through ages of erosion. As a rule, these materials are rudely stratified, the coarsest, heavier gravels lying nearest to the mouths of the cañons. In a well 90 ft. deep, near the University, on the mesa about five miles from the channel of the Rillito, the following beds were passed through, but the strata were not sharply defined:

Section of the Mesa, to Water-Level.

	Feet.
Soil, sandy and porous,	1
Caliche,	6
Sand and gravel,	12
Argillaceous earth (red),	2
Sand (red),	2
Caliche, soft and amorphous,	2

	Feet.
Sand, hard,	6
Sand and gravel ("cemented"),	3
Sand cemented and aggregated in lumps,	11
Argillaceous earth, red,	3
Argillaceous earth and sand, red,	30
Sand and boulders mixed,	8
Water in sandy bed,	4

Most of the sand and gravel not enveloped in *caliche* was found well filled with small sparkling crystals of calcspar, which appears to be the cementing substance holding the grains of sand together.

Wherever these gravels have been pierced by wells in the vicinity of Tucson, an abundance of water has been found at a depth of from 80 to 90 ft., or even less, depending upon the altitude of the surface. This water seems to be inexhaustible; at least it is in such quantity, and flows so freely, that the pumping-plant at the University can be run continuously, discharging a 6-inch stream, without exhausting the supply in the well.

The general composition of this underground water is shown in the annexed table, compiled from the records of the chemical laboratory of the University of Arizona.

Analyses of Well-Waters of Tucson and Vicinity—Parts Per 100,000.

	Two Miles N. of University.	R. R. Well.	Irrigating Well.	Tucson City Water.	Hoff's Well.	Oracle.	Tucson Water Works.
Total Soluble Salt	24.5	42.0	26.0	65.0	45.0	39.0	42.8
NaCl	1.4	3.0	3.0	4.4	4.5	3.4	3.95
$(Na, K)_2SO_4$	3.1	15.2	6.5	26.8	13.5	10.6	16.92
Na_2CO_3	2.0	1.3	1.0	1.8	1.5	2.0	......
$(Ca, Mg) CO_3$	9.0	15.5	9.5	22.0	16.5	14.5	18.56
$CaSO_4$	1.0	trace	0.5	0.0	0.5	0.5	1.74
SiO_2	3.0	2.0	2.0	2.0	2.0	2.0	3.10

It is probable that, in the course of the underground flow of the water from the higher levels towards the Santa Cruz, there are considerable areas of basin-shaped depressions in the bed-rocks, where water accumulates and is more sluggish in its movement. So, also, there may be ancient channels, determining a more rapid flow than in other places; in each case there

may be a difference in the amounts of solid matters held in solution.

There has been much speculation in regard to the origin of the *caliche*. It has been generally assumed to be a deposition from some ancient lake, or body of water, once covering the area in which it is found. But such a theory is untenable when all the phenomena are considered. The formation is clearly the result of the upward capillary flow of calcareous water, induced by constant and rapid evaporation at the surface in a comparatively rainless region.

With a constant supply of phreatic* calcareous water, the second great essential factor in the formation of *caliche* is the continued desiccating atmosphere—a condition which prevails, with only short and temporary exceptions, throughout the year. The desert and semi-desert regions of Arizona are characterized meteorologically by the unusual dryness of the air and its capacity for the absorption of moisture, and the maintenance of continued evaporation from the soil, which determines a constant upward movement of the phreatic water. The occasional rains in midsummer and midwinter do not penetrate to great depths, but are sufficient to leach out the soil to the depth of a few inches or feet, turning the calcareous solution back and downwards, and producing the denser upper crust, where it meets the upward flow.

Such I conceive to be the origin of the *caliche*. It may be called a subterranean deposit of travertine; but it is not the result of a flow from springs, or from any source at the surface, or by the lateral movement of water. Unlike ordinary travertine, it is the result not of descending but of ascending currents. The ordinary conditions of vadose circulation are reversed. The *caliche* is a fine example of the formation of extensive calcareous strata in the midst of pre-existent beds, not by metasomatic processes, but by precipitation from sources below.

This explanation may apply equally well to some other subterranean deposits in arid regions, where the upward flow is maintained in excess of any downward percolation. It may apply, possibly, to the origin of soda-niter, of some beds of gypsum, and of some of the metallic sulphides. In fact, the phenomena of deposition of ores in mineral veins are here

* *Eaux phréatiques*, Daubrée, *Les Eaux Souterraines à l'époque actuelle*, i., 19.

repeated in kind, though not in form, over broad and approximately horizontal areas, so as to make bedded deposits instead of fillings of fissures.

Surface-deposits of soluble salts, such as the chlorides, sulphates and carbonates of the alkalies, are familiar to all residents of arid regions. The "black-alkali" of the Salt River valley in Arizona, so injurious to vegetation, is an example of the concentration, by evaporation at the surface, of solutions of carbonate of soda. The white efflorescences on the soil in the dry season, known to the Mexicans as *tequisquita*, are familiar examples. These deposits become snow-white in a dry time, and quickly disappear into the soil during a rain-storm.

The presence of *caliche* in the soil over extended areas in the arid regions I regard as good evidence of the existence of subterranean water. The possibility of a change of conditions *since* the deposit of the *caliche* should, however, be considered.

I have elsewhere directed attention to the possible enrichment of the upper portions or croppings of mineral veins by the upward flow of solutions formed by the decomposition of the ores above the permanent water-level in arid regions, and, conversely, the impoverishment of the croppings of lodes in regions of abundant precipitation, where downward circulation predominates. The copper-deposits at Ducktown, Tennessee, afford striking illustrations of the latter process.

The Character and Genesis of Certain Contact-Deposits.*

BY WALDEMAR LINDGREN, WASHINGTON, D. C.

(Richmond Meeting, February, 1901.)

CONTENTS.

I.—Character of the Deposits.

1. *Principal Features.*

In many schemes of classification and description the term *contact-deposit* has been somewhat loosely applied to all accumu-

* Published by permission of the Director of the U. S. Geological Survey.

lations of useful minerals (other than those of unquestioned sedimentary origin) which are enclosed between two different rocks. As thus used, the term may include deposits of widely differing origin, and, unless qualified, is not in place in a genetic classification. The present paper deals with a special class of contact-deposits.

In many geological provinces, granular igneous rocks, such as granite, diorite and syenite, have broken through and invaded sedimentary rocks. The molten magma may in part have reached the surface and there solidified with relative rapidity as a lava. The largest masses of it, however, did not reach the surface, but cooled very slowly at considerable depth under great pressure, and eventually consolidated into a rock of granitic texture. Uplifts and extensive erosion may have followed; and at the present day, in many places, thousands of feet of material have been removed, bringing to the surface the intrusive granular rocks and their once deep-seated contacts with the sedimentaries which they shattered at the time of intrusion. Along these contacts, bodies of useful minerals are often found, most commonly where the sedimentary rock is limestone, or, at least, calcareous.

All the world over, this group presents certain characteristics, the more essential of which are the following:

Form.—The deposits generally follow the contact, but are extremely irregular in detail, and almost always very bunchy. No regular law has been recognized as governing the form of the ore-bodies, which are sometimes lenticular masses.

Position.—The minerals generally occur in the limestone or calcareous rock, immediately on the contact, from which they rarely extend more (usually much less) than a hundred feet.

Constituent Minerals.—The gangue contains garnet, wollastonite, epidote, ilvaite (lievrite), amphibole, pyroxene, zoisite, vesuvianite, quartz and calcite, rarely fluorite and barite. The ore-minerals are specularite, magnetite, bornite, chalcopyrite, pyrite, pyrrhotite, and, more rarely, galena and zincblende. The sulphides may carry some gold and silver, usually more of the latter than of the former, but are rarely rich. Tellurides are unknown. The characteristic feature is the association of the oxides of iron with sulphides, a combination practically un-

known in fissure-veins,* and further the presence of various silicates of lime, magnesia, and iron. The deposits are throughout metasomatic, having been formed by the replacement of limestone; and the filling of open spaces is almost entirely absent. On account of the great solubility of the limestone, well-developed crystals of the gangue minerals are very common.

Exceptions.—There are some classes of deposits which, though presenting a certain similarity to this type, must be strictly separated from it. Among these are contact-deposits between limestone and igneous rocks which carry as metasomatic products (besides galena and zincblende) sericite, dolomite, siderite and quartz, and which, upon close investigation, are usually found to be related to fissures and faults. Further, certain deposits of iron-ores, associated with limestone and with garnet-pyroxene-amphibole gangue, but without any apparent close relation to intrusive rocks. This kind will be referred to again in this paper in the discussion of the genesis of the deposits.

2. *Literature.*

Though the contact-deposits here described are not very abundant, and rarely of great economic importance, they could not long escape the notice of mining geologists. In 1865 B. v. Cotta† described the celebrated mines of the Banat, in Austria, and expressed the opinion that all of them were due to the action of intrusive rocks on a probably Mesozoic limestone. Regarding some of these deposits, this view has lately been opposed by H. Sjögren,‡ who, however, admits that others in the same vicinity may stand in causal relation to the intrusion.

To v. Groddeck belongs the credit of having recognized these deposits as a separate class,§ which he calls the *Kristiania type*, and characterizes as follows:

"Siderite, magnetite, chalcopyrite, bornite, pyrite, galena, zincblende, etc., accompanied by garnet, amphibole, wollastonite, axinite, etc., mingled in very different proportions, forming nests and stocks at the contact of eruptive rocks with granular limestone, or often wholly within the latter. These deposits thus

* Specularite and arsenopyrite are both known from cassiterite-veins, which, however, in origin, stand close to pegmatite-veins and certain contact-deposits.

† *Erzlagerstätten im Banat und in Serbien*, 1865.

‡ *Jahrbuch d. K. K. Geol. Reichsanstalt*, 1886, xxxvi., pp. 607–668.

§ *Die Lehre von den Lagerstätten der Erze*, 1879, p. 260.

belong in the sphere of contact-metamorphism, and may be briefly characterized as 'contact-deposits.'"

Among the examples are mentioned the contact-deposits of the vicinity of Kristiania and those in the Urals (Bogoslowsk). Several others are also included which are more doubtful (Pyrenees, Rodna, Rezbanya, Offenbanya, the Banat and Schwarzenberg), and part of which seem to be due to regional metamorphism, or to the action of ascending thermal waters at the contact of lavas and limestone. V. Groddeck apparently fails to recognize that the presence of *intrusive* igneous rocks is necessary to develop this type of deposits. Siderite, mentioned in his definition as one of the characteristic minerals, does not occur in the typical examples, and seems to be neither common nor essential.

De Launay* also describes similar deposits, but includes under the heading several other deposits not so clearly belonging to the same category, and hardly recognizes the importance of the presence of intrusive rocks. In addition to the well-established examples from v. Groddeck, de Launay adds excellent descriptions of the mines of Mednorudjansk and Ekaterinenbourg in the Urals, which leave little doubt that these, also, should be enrolled under the Kristiania type.

In Prof. Kemp's classification,† the following division is found: "Contact-Deposits. Igneous rocks always form one wall. Fumaroles (Greisen)." This is evidently to include several different things under one heading. On p. 222, however, Prof. Kemp recognizes the importance of the type outlined in this paper, one example of which is mentioned, namely, that of the Seven Devils district, Idaho. Relating to the same subject we find (p. 69) the following direct utterance:

"In the more characteristic 'contact-deposits' the igneous rock has apparently been a strong promoter of ore-bearing solutions, and has often been the source of the metals themselves. This form of deposit becomes, then, an attendant phenomenon of, or even a variety of, contact-metamorphism."

Prof. Vogt describes contact metamorphic desposits in several of his recent papers.‡ In that of 1894 the contact-deposits

* *Traité des gîtes métallifères*, Paris, vol. ii., pp. 245–258.

† *Ore-Deposits of the United States and Canada*, J. F. Kemp, 3d ed., p. 58.

‡ J. H. L. Vogt. *Die Kieslagerstätten Röros-Sulitelma und Rammelsberg, Z. f. prakt. Geol.*, 1894, p. 177. *Zur Classification der Erzvorkommen, Z. f. prakt. Geol.*, 1895, p. 154. *Concentration des Metallgehaltes zu Erzlagerstätten, Z. f. prakt. Geol.*, 1898, p. 416.

near Kristiania are described on the basis of his own investigations and of the previous work of Kjerulf.* These deposits, which are small and do not have much economical importance, occur in the majority of cases exactly on, or very close to, the contact of syenitic rocks and Silurian limestone and slates, along which they are found in great numbers and of irregular form. The mineral aggregates sometimes show a banding parallel to the stratification, and are only found in the sedimentary rock, not in the syenite. The gangue-minerals are garnet, amphibole, pyroxene, mica, epidote, vesuvianite, scapolite, chiastolite, quartz, calcite, also fluorite and axinite. As ore-minerals appear magnetite, hematite, chalcopyrite, galena, zincblende, and, more rarely, minerals containing bismuth, arsenic and antimony. Besides this locality are mentioned others from the Pyrenees, Banat, Pitkäranda (Finland) and Queensland.

In the treatise of Phillips–Louis† we find in the preliminary part no mention of this type of contact-deposits; and, in the second part, giving detailed descriptions, such "contact-deposits" as Leadville, Rodna and the Banat are treated together without genetic distinctions.

3. *Geographic Distribution.*

Deposits of this type are fairly common in America, though little attention has been directed to them, probably because of their smaller economic importance. As might be expected, most of them are found in the regions of the Pacific Cordilleras, where great intrusions have been followed by uplifts and enormous erosion. They are generally found at the contacts of quartz-monzonites, granodiorites, quartz-diorites and diorites with limestone. Besides the gangue-minerals mentioned above, the characteristic ore-minerals are specularite or magnetite with bornite or chalcopyrite. A smaller group is distinguished by the additional appearance of galena and zincblende which, in places, may overshadow the copper minerals in economic importance.

California.—The great area of granodiorite in the Sierra Nevada, accompanied by smaller areas of quartz-diorite, breaks through the Paleozoic and Mesozoic sedimentary rocks. Along

---

* *Udsigt over det sydlige Norges Geologi*, Kristiania, 1879.

† *A Treatise on Ore-Deposits*, London, 1896.

the contacts thus presented, ore-deposits of the type here described are rarely met with, perhaps because limestones and calcareous rocks are not very abundant. However, on the area of the Colfax Folio of the U. S. Geol. Survey, about 10 miles north of the railroad station of Emigrant Gap, Nevada co., a mass of probably carboniferous limestone has been greatly contact-metamorphosed and filled with garnets, etc., but no sulphides appear in it. Along the contacts of the smaller intrusive areas of granodiorite down on the western slope of the Sierra Nevada small copper-deposits are occasionally found. Near Fairplay, Eldorado co., at the contact of granodiorite and limestone in the cañon of the Cosumnes river, garnets and epidote occur, and, intergrown with these, small masses of bornite and chalcopyrite.

In Alpine co., 12 miles due south of the southern end of Lake Tahoe, an area of sedimentary calcareous rocks of uncertain (probably Triassic) age, about 1.5 mile long and 0.5 mile wide, occurs embedded in granodiorite, which is the prevailing rock in that vicinity. The locality is in the upper part of Hope valley. At several places along the contacts, mineralization has taken place. The prospects were visited by Mr. H. W. Turner in 1888, and by myself in 1895. At Rodgers' mine* the strata consist of alternating thin beds of quartzite and limestone, the latter carrying the principal value. The ore-bearing strata are in places 100 ft. thick. About $100,000 worth of ore is said to have been extracted from this place some three or four decades ago. The ore-minerals consist of pyrrhotite, chalcopyrite and bornite, and contain gold as well as some silver. The principal gangue-mineral is garnet.

On the east slope of Stevens Peak, in the same area, a stratum of limestone near the contact is very crystalline, and contains garnets and zincblende.

At Barnes' prospect, in the same area, a wedge of limestone, projecting into the surrounding mass of granodiorite, is highly crystalline and filled with garnets, amphibole, and other contact-minerals. Of ore-minerals, magnetite and chalcopyrite as well as bornite were found; these are reported to contain some gold and silver.

Idaho.—A number of deposits of the Kristiania type are believed to occur in this State, though their true nature has

---

* MS. notes by Mr. H. W. Turner.

rarely been recognized. Position and mineral association indicate that the lead-zinc deposits at South Mountain, Owyhee co., are true contact-deposits, though when visited by Mr. F. C. Schrader* the developments did not permit any exact study of structural relations. The ores occur on the contact of limestone and diorite or granite; the ore-minerals are argentiferous galena, zincblende, and a little chalcopyrite and magnetite; the gangue being garnet, quartz, actinolite and the typical contact-mineral ilvaite or lievrite. According to the description of Mr. G. H. Eldridge,† certain deposits on Sheep Mountain in central Idaho very likely belong to this type.

Most characteristic are the contact-deposits of the Seven Devils, briefly described in a recent report.‡

In the Seven Devils district, and in the adjacent Snake River cañon, copper-deposits are very abundant. There is, in that vicinity, an extensive series of Triassic basic lavas, with intercalated layers of slate and limestone. There are also diorites, intrusive in these beds. All of these igneous rocks apparently contain copper which was easily concentrated into deposits of various kinds; some, fissure-veins; others, zones of impregnation; others, contact-deposits. In the locality of the original discovery in the Seven Devils, the copper occurs in typical contact-deposits. Small masses of limestones are embedded in a later, intrusive diorite; at the contact, and usually in the limestone, are found irregular bodies and bunches of bornite, chalcocite, and a little chalcopyrite, containing, say, 10 oz. of silver and a little gold per ton. The limestone at the contact is very crystalline and contains, associated with the ores, abundant garnet, epidote, quartz, calcite and specularite. The copper sulphides, as shown by their intergrowth, were certainly formed at the same time as the gangue-minerals. The epidote, specularite and garnet, as described by Dr. Palache,§ present clear evidence of simultaneous crystallization. At the Peacock mine a large body of medium-grade ore of this character was embedded in diorite. No limestone showed here; but I am informed that a lower tunnel has lately encountered limestone below the croppings.

---

* W. Lindgren, *Silver City and DeLamar*, *20th Ann. Rep. U. S. Geol. Sur.*, Part III., pp. 187–189. † *16th Ann. Rep. U. S. Geol. Sur.*, Part II., p. 258.

‡ W. Lindgren, *20th Ann. Rep. U. S. Geol. Sur.*, Part III., p. 249.

§ *Am. Jour. Sci.*, 3d Ser., vol. viii., p. 299, Oct., 1899.

Other claims in which the ore occurs on the contact of limestone and diorite are the White Monument, Alaska, Blue Jacket, Helena and Decorah. Considerable masses of ore have been exposed at some contacts, though the distribution is extremely irregular. In the Blue Jacket, a rich body of bornite and chalcocite was lately found; and it is reported that 500 tons of 40-per cent. ore has been shipped from this mine during the past summer. During 1900, the Boston and Seven Devils Copper Co. shipped from the Peacock and other claims 260 tons, containing 23 per cent. of copper, besides 8 oz. of silver and 0.04 oz. of gold per ton.

Still another copper deposit in Idaho which appears to belong to this type is the White Knob mine, near Houston, in Lost River valley. Mr. W. Darlington, the general manager of the company, has kindly furnished the following information. The ore occurs as a deposit between granite and limestone; the trend of the contact is N. and S., the limestone lying to the E. and the granite to the W. On the surface the ore-bearing zone is 1200 ft. in length, and (as a maximum) 400 ft. in width. The minerals are hematite, magnetite, chalcopyrite, pyrite and a little galena, in a gangue of garnet and coarsely crystalline calcite. A porphyry dike also occurs on the contact, complicating the geological relations. The oxidized zone is very deep, water not having been encountered until the depth of 600 ft. was reached in the shaft.

Arizona.—It is well known that many and very important copper-deposits occur associated with limestone and igneous rocks in Arizona. The descriptions published seem to indicate that few of them, if any, are contact-deposits of the Kristiania type. In most of them, also, the zone of oxidation is very deep and their original character has been greatly altered.

British Columbia.—Recent literature describing the copper-deposits of Vancouver and Texada islands points without doubt to the existence of numerous and important contact-deposits in those localities. Already indicated by Mr. Carlyle,* this is confirmed by Mr. Wm. M. Brewer†. The deposits always occur in or very near the contacts between limestone and gabbro or diorite. The mineral association is magnetite, chalcopy-

* *Report of the Provincial Mineralogist,* 1897.

† The Copper-Deposits of Vancouver Island. *Trans.*, xxix., 483. *Eng. & Min. Jour.*, 1900, Apr. 21, May 5, July 14.

rite, hornblende and garnet. In some places the magnetite predominates, almost to the exclusion of the chalcopyrite.

Northwest Territory.—Mr. R. H. Stretch has recently described* interesting deposits on the Upper Yukon, which, to judge from the excellently presented data, are contact-deposits of the Kristiania type. Mr. Stretch, however, it is fair to say, does not consider them as due to contact-metamorphic origin, but as a result of later mineralization. The locality is a few miles west of White Horse Rapids, lat. 60° 40′, long. 135°.

The prospects are found along a narrow strip at the base of a mountain range, consisting chiefly of limestone. This base is a granite plateau which Mr. Stretch thinks underlies limestone; in fact, a few patches of limestone remain on the plateau. The ores occur at the contact of the two rocks, or in seams of varying size in the granite. Two classes of ores are found: (1) large masses of specularite or magnetite, carrying a moderate amount of copper; (2) outcrops of smaller dimensions, in which the ore is bornite with a little chalcopyrite. Many of these prove to be connected with E.–W. seams penetrating the granite, but nowhere show evidence of massive vein-structure.

At all the localities, epidote and lime-garnets are present. The bornite contains some gold and silver; and a little molybdenite is also found. Dikes of granite occasionally cut the limestone.

Mexico.—From a perusal of recent geological literature of Mexico, it is clear that contact-deposits of the Kristiania type are very abundant there—more so than in other parts of North America. In a review of the gold-deposits of the republic, Mr. Ordoñez† says:

"Examples of another type of ore-deposits are found in regions where sedimentary Mesozoic rocks appear, that is, on the eastern slopes of the Sierra Madre, towards the Gulf of Mexico. These consist of contact-veins between generally Cretaceous limestones and eruptive granitic rocks, nearly always diorite. The limestones are metamorphosed at the contact, and the copper minerals containing gold occur irregularly distributed in contact-metamorphic silicates, such as garnet and epidote.

"Such deposits exist at Encarnacion, district of Zimapan, also in the vicinity of San José del Oro; further, at San José, Central district, State of Tamaulipas, as well as at many other places."

* *Eng. & Min. Jour.*, Sept. 8, 1900. *Notes on the White Horse Copper-Belt.*

† *Note sur les gisements d'or du Mexique*, Mexico, 1898, p. 233.

Aguilera and Ordoñez, mentioning several localities in their sketch of the Geology of Mexico,* write as follows:

"In the region of Mazapil, Zacatecas, an extensive formation of Cretaceous limestone is cut by dioritic rocks. Near the contact extend very important deposits, worked during many years. The contact is marked by a conversion of the limestone to marble."

"Chalcopyrite, always accompanied by grossularite (garnet), and usually by hematite, occurs in Cretaceous limestone, and its appearance is due to the eruption of igneous rocks, as may be seen at San José in the Sierra San Carlos, in Tamaulipas, in which copper-minerals, accompanied by magnetite, appear at the contact of the andesitic diorite."

A similar deposit from the State of Chiapas is interestingly described by Mr. E. T. McCarty.† Here limestone of unknown age is invaded from below by rocks called trap, syenite or dolerite. At the contacts the limestone is largely converted into wollastonite and garnet, besides a little quartz, chalcedony, calcite and aragonite. This contact-metamorphosed limestone contains, partly scattered through it, partly in more concentrated but very irregular "ore-channels," auriferous and argentiferous bornite, as well as some chalcopyrite, enargite, galena and linnæite. The average ore consists of 90 per cent. of garnet with 10 per cent. of quartz and chalcedony, carrying from 3 to 4 per cent. of copper and from 6 to 8 oz. silver, and from $6 to $20 in gold, per ton. The gold is in part free and visible. Regarded as a whole, the ores appear in curved planes, which probably follow the outline of the underlying intrusive. The total width of the ore-bearing limestone is about 30 ft., and within this distance are two ore-bearing streaks. Very often the ore lies directly on the contact.

Other Countries.—In the foregoing brief notes I have attempted to call attention to the occurrences of this type in America only. But short and incomplete descriptions, found here and there in the literature of the subject, make it more than likely that such contact-deposits occur in West Australia, Queensland, South Africa and China. From the latter country,

---

* *Bosquejo geológico de México*, Mexico, 1897, pp. 68, 222. *Boletin del Instituto geol. de México*, Nos. 4, 5, 6.

† "Mining in the Wollastonite Ore-Deposits of the Santa Fé Mine, Chiapas, Mexico," *Trans. Inst. Min. and Met.*, London., vol. iv., pp. 169–189 (1895-1896). See also H. F. Collins, *Id.*, Feb., 1900; and Mr. Collins's "Note on Cheap Gold Milling in Mexico," on a later page of this volume.

for instance, F. L. Garrison* describes lead- and zinc-deposits in contact-metamorphic limestone, near granite.

II.—Origin of the Deposits.

The deposits of the Kristiania type may be separated into several subdivisions, according to the prevalence of certain metallic minerals. Thus we have iron-deposits, carrying chiefly magnetite and specularite; copper-deposits, characterized by bornite and chalcopyrite; and finally zinc-lead deposits, containing galena and zincblende. These three groups are connected by transitional examples. In all of them the metallic-minerals are intergrown with the various gangue-minerals,—garnet, epidote, wollastonite, etc.—in such a manner that they must be considered as having a simultaneous origin. The theory of a subsequent introduction of the metallic ores is decidedly untenable. Since, on the other hand, the garnets and other gangue-minerals stand in unquestionable relation to the contact-metamorphic action, a theory of the origin of these deposits certainly becomes a branch of the study of contact-metamorphism.

1. *Contact-Metamorphism.*

The peculiar action of intrusive igneous bodies upon adjacent sedimentary rocks is a well-known fact in geology and petrography. The sedimentaries usually suffer a more or less intense metasomatic alteration, termed contact-metamorphism. Surface-eruptions (lavas), as a rule, exert no such intense action, though a certain baking or partial melting of the immediately adjoining rock may sometimes be recognized. The metamorphism exerted by intrusive rocks is characterized by a gradually fading alteration of the sediments, sometimes extending over a width of several kilometers. The contact of the altered rocks with the intrusive is usually sharp, a melting of the former being rarely if ever noticed. Slates and shales in the immediate vicinity of the intrusive rock are changed to highly crystalline schists or massive crystalline rocks, containing andalusite, feldspar, cordierite, garnets, etc.; further away, slighter recrystallization results, with development of mica and accumulation of the carbon of the shales in little knots and masses. In general, there is no considerable addition or

* *Mining and Metallurgy*, Feb. 15, 1891, p. 107.

subtraction of material during the metamorphism. Limestone usually suffers a stronger contact-metamorphism and becomes a coarse-grained marble. Garnet, wollastonite, amphibole, pyroxene, epidote, etc., often well crystallized in large individuals, form in it. In this case there is usually an addition of silica and a loss of carbon dioxide. In many places the contact-zone has received an access of certain minerals containing boron and fluorine not contained in the unaltered rocks; the most common of these are tourmaline and topaz. Oxides and sulphides, such as magnetite, specularite, ilmenite, pyrite and pyrrhotite, are often contained in contact-metamorphic slates and schists.* Magnetite, pyrite and pyrrhotite have been observed in limestones (Morbihan, France);† and the Devonian limestones at Rothau, in the Vosges, are metamorphosed for a few hundred feet from the contact, and contain pyroxene, garnet, epidote and a little galena.‡

Brögger, in his studies of the contact-metamorphic rocks near Kristiania,§ remarks:

> "Pyrrhotite appears abundantly in the altered rocks, and is certainly a mineral formed during the contact-metamorphism, for it does not occur in the unaltered rocks. It is not easy to say whether an addition of material has really taken place, or the mineral represents a recrystallization of finely distributed pyrite. Strongly in favor of the hypothesis of direct addition is the fact that large accumulations of pyrrhotite exist in the contact-metamorphic rocks—so large, indeed, that mining has been attempted in places." . . . . "As already indicated by Kjerulf, we must consider the many small ore-deposits occurring along the contacts of granite and syenite with Silurian rocks as contact-formations; and they should really be included in any study of the contact-metamorphism of this region."

The same opinion is strongly held by Prof. Vogt.

Cause of Contact-Metamorphism.—Petrographers in general agree that contact-metamorphism is due to the heat of the molten magma combined with the action of the water which it contains. It is well known that during and following volcanic eruptions, water, hydrogen sulphide, sulphur dioxide and carbon dioxide, as well as compounds of chlorine, fluorine and boron, are emitted. While some of these may result from the contact of the lavas with water and other materials, which they encounter at their eruption, it is extremely probable that

* F. Zirkel, *Lehrbuch der Petrographie,* Leipzig, 1894, ii., p. 97.

† *Loc. cit.*, p. 113.

‡ *Loc. cit.*, p. 115.

§ *Die Silurischen Etagen,* 2 and 3. Kristiania, 1882, p. 369.

a large proportion of them is derived from the magmas themselves.* This opinion is supported by excellent geological authority—for instance, by Prof. T. C. Chamberlin, who says:†

> "It is a familiar fact that enormous quantities of gases are ejected from volcanoes. It has been assumed that these have a surface-origin, and this is true in part; but, on the other hand, there is abundant ground for the belief that another notable part is brought from the interior, and is a real contribution to the earth's atmosphere and hydrosphere."

This is confirmed by the well-known fact that deep-seated igneous rocks contain much carbon dioxide, and also, sometimes, sulphides; while both are much less common in extrusive lavas.

No matter by what force, the igneous rocks have certainly been brought up from deeper levels. If we admit that they contained dissolved various substances, such as water, carbon dioxide, and compounds of sulphur, chlorine, boron and fluorine, with various metals, it follows that the diminution of pressure caused by the rise to higher levels will gradually result in the escape of these compounds, which are so much more volatile than the other constituents of the magma. The higher the rise of the magma, the more complete the liberation of these substances. In what form they will escape, depends on the critical temperature of the substances and the pressure at the point of issue. We may assume with great confidence that at the contacts of intrusive rocks with a sedimentary series the temperature usually exceeded 365° C. and the pressure 200 atmospheres. Under these conditions the water, and likewise most of the more or less volatile compounds mentioned, would exist as a gas; in other words, pneumatolytic conditions would prevail. The water and accompanying compounds would be released from the magma and would penetrate, more or less energetically, the adjoining rocks for a varying distance. It does not seem probable that atmospheric water could have gained access to the contacts during the period of consolidation. Both the heat of the igneous rock and the pressure of the volatile compounds, striving to free themselves from the association with the magma, would prevent this.

---

* Braun's *Chemische Mineralogie*, Leipzig, 1896, pp. 283–287.

† *Jour. of Geol.*, vii., p. 559, 1899. (Quotation slightly condensed.)

The escape of the gases may be facilitated by cracks and fissures, and the emanations may be gradually taken up by circulating surface-water, which then will appear as thermal springs. Among the supporters of this view may be mentioned Profs. Rosenbusch* and Chamberlin.†

Admitting the tendency of the more volatile constituents of the magma to leave it under relaxing pressure, and knowing the tendency of the "mineralizing agents" to form volatile compounds with various metals, it does not seem so very surprising that mineral-deposits of various kinds should be formed during the contact-metamorphism. The only thing needed is a substance causing their deposition, and thus preventing their escape to join the circulating surface-waters. Such a substance is limestone. A chemical reaction appears to take place between the substances leaving the magma and the carbonate of lime, causing the deposition of new minerals and the liberation of carbon dioxide.

To some degree, this is confirmed by the experiment of Sénarmont,‡ who obtained crystallized specularite by prolonged action of a solution of ferric chloride on calcium carbonate, at 300° C., in a closed tube. Further experimental tests in this direction would be most desirable. Also interesting and pertinent to this question is the experiment of Doelter,§ who obtained magnetite by cooling limestone in molten basaltic rock; this magnetite was clearly derived from the basalt, and was found segregated on the contact.

The genesis of the contact-deposits of the Kristiania type thus seems to be due to aqueous gas above the critical temperature, which was more or less laden with metallic compounds, and, under heavy pressure, penetrated the limestone adjacent to the igneous intrusive body. The temperatures must have been very high, but generally below the melting-point of ordinary rocks. Carbon dioxide was evidently not an active reagent; for the principal reaction consists in its expulsion from the limestone. Under the prevailing conditions, the metals cannot reasonably be supposed to have been derived from the limestone. Everything points to the conclusion that the metallic substances were given off by the cooling magma.

---

* *Elemente der Gesteinslehre*, Stuttgart, 1898, p. 42.

† *Loc. cit.*, p. 559.

‡ Braun's *Chemische Mineralogie*, Leipzig, 1896, p. 268.

§ *Loc. cit.*, p. 253.

This is also, in general, the conclusion of all who have carefully examined these deposits, from v. Cotta and v. Groddeck to Prof. Vogt, who has more recently written on the subject.*

The ores were deposited during the consolidation of the magma. The larger part of them occur in the limestone; but it is not inconsistent with the theory here developed that some ore may also be occasionally found in the adjacent igneous rock. The deposits are entirely metasomatic. The ore and gangue replaced limestone; and there were, as a rule, no open cavities to be filled.

2. *Similar Deposits of Different Origin.*

As mentioned before, there are certain deposits which owe their origin to dynamo-metamorphic or regional-metamorphic processes, and which show a considerable similarity to the Kristiania type. Indeed, the minerals of regional-metamorphism are generally identical with those of contact-metamorphism, and the agencies are evidently similar.† We may suppose that in the latter case they consisted of water under considerable pressure and at a fairly high temperature; but it does not seem at all likely that the conditions were pneumatolytic, or that the temperature approached that of the intrusive contacts. Characteristic for the regional-metamorphic deposits are (1) the association of oxides of iron with sulphides so utterly foreign to the deposits formed by ascending waters, and (2) the minerals (garnet, amphibole, epidote, etc.) which distinguish the contact-deposits. Bornite, so common in the latter, does not, however, seem to occur in regional-metamorphic deposits. In regional-metamorphism there has been but little transportation of substance; the masses of ore are rather old disseminations, or originally sedimentary deposits, concentrated and rearranged under the influence of heat and permeating moisture. As examples of deposits of regional-metamorphic origin may be mentioned the principal iron-ore deposits of Sweden and those of Michigan.

3. *Genetic Classification.*

The form of mineral deposits is sometimes characteristic, but at no time essential. Hydrothermal deposits are usually tabular,

* *Z. f. prakt. Geol.*, 1898, p. 416.

† See, for instance, C. R. Van Hise, *Bull. Geol. Soc. Am.*, vol. ix., p. 311.

but this is only because ascending hot waters usually find it convenient to follow the easy path of open fissures.

It seems appropriate to make a separate division into *hydrothermal deposits* caused by hot, ascending waters, and characterized by certain very diversified, but still similar, metasomatic alteration, which I have elsewhere described more in detail.* No doubt these will be found to merge gradually into the deposits caused entirely by cold surface-waters.

A second division should be made to include "*contact-metamorphic" deposits*, wholly differing in mineral association and metasomatic character from the first division. Between the two divisions, but more closely related to the hydrothermal class, stand the cassiterite veins. A third division may be made to include the *dynamo-metamorphic and regional-metamorphic deposits*, similar to the contact-deposits in mineral association, but chiefly consisting of concentrated old impregnations, or old sedimentary-deposits enriched by metasomatic processes, very different from those caused by the strong solutions of hydrothermal waters. Transitions are to be found, no doubt, between the hydrothermal and the dynamo-metamorphic deposits, but this does not diminish the value of these principal divisions. It is worthy of note that a very large proportion of the total production of gold and silver is derived from hydrothermal deposits.

Prof. Van Hise has recently, in a most instructive and interesting paper,† suggested a classification in which, at first glance, there would seem to be no place left for deposits of the kind here described. It is probable, however, he did not intend to limit the "igneous" deposits to those consolidated from a molten magma, as might be inferred from his paper (*Trans.*, xxx., pp. 30–177), for on page 174 is the following statement:

> "I even hold that there are gradations between ore-deposits which may be explained wholly by igneous agencies and those which may be explained wholly by the work of underground water."

From other papers it is also clear that Prof. Van Hise admits that emanations from intrusive magmas may mingle with the waters of atmospheric origin, and that deposits may be formed in this way; for he says‡ that

---

* "*Metasomatic Processes in Fissure-Veins*," *Trans.*, xxx., 578.

† "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 27.

‡ 16*th Ann. Rept. U. S. Geol. Sur.*, Part I., p. 687.

"It is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. . . . If this be so, there will be all stages of gradation between true igneous injection and aqueous cementation, and all the various phases of pegmatization may thus be fully explained."

In the succeeding paragraph in the same paper, observations in the Black Hills of Dakota are recorded, which appear to show that a regular transition exists, from pegmatitic veins to normal quartz-veins, the latter appearing furthest away from the igneous core which furnished the material for the pegmatitic veins.

4. *Relation of Pegmatite-Veins to Ore-Deposits.*

The pegmatite-veins contain coarse granular aggregates of quartz and feldspar usually characterized by simultaneous crystallization; associated with these are a great number of rarer minerals, such as zircon, apatite, specularite, tourmaline, topaz, beryl, and a vast number of minerals containing the rare earths. Their origin has for a long time been a subject for discussion, both consolidation from a molten magma and aqueous deposition being suggested. The modern view of their genesis, represented by Messrs. Brögger and Rosenbusch, is that, while they may be to some extent the result of consolidation from a molten state, they are very largely of pneumatolytic origin.

The pegmatite-veins are formed *after* the consolidation of the main mass of the igneous rock, and are to be considered as the last results of magmatic differentiation. That they are so much richer in the rarer minerals than the igneous rock with which they are associated, is to be explained by the concentration of the escaping volatile compounds of boron, chlorine, fluorine and sulphur into a smaller volume of residual magma.* A migration of these volatile compounds into the surrounding rock may sometimes be noted. Thus, for instance, Prof. Patton describes,† from Colorado, tourmaline impregnating schist for 2 or 3 ft. on both sides of a 10-ft. pegmatite-vein, which itself only carries a smaller percentage of that mineral.

Sulphides, as well as oxides, are sometimes found in pegmatite-veins, though I know of no instance of economically valu-

* W. C. Brögger, *Die Mineralien der Südnorwegischen Pegmatitgänge, Zschr. f. Kryst. und Min.*, Bd. xvi., p. 213.

† *Bull. Geol. Soc. Am.*, vol. x., pp. 21–26, 1899.

able masses. Among the minerals are cassiterite, wolframite, specularite, löllingite ($FeAs_2$), molybdenite, zincblende, galena and chalcopyrite. At least one of these, löllingite, Brögger regards as certainly belonging to the earliest period of pegmatite formation (magmatic consolidation, accompanied by pneumatolytic action); while others are regarded to have been formed by a combination of pneumatolytic and aqueous agencies.

It has been noted that many pegmatite-veins are exceptionally rich in quartz, and it has been suggested that normal quartz-veins may form transitions into pegmatite-veins. Occurrences apparently confirming this view have been recorded by many reliable observers, such as G. H. Williams,* Van Hise,† Crosby,‡ Fuller and Spurr.§ Mr. Spurr explicitly declares his belief that, in the Yukon district, pegmatite-veins form transitions into gold-bearing quartz-veins; these latter, he thinks, have been "deposited from (magmatic) solutions so attenuated that they may best be described as waters highly heated and heavily charged with mineral matter in solution."

These observations are highly interesting. It is quite possible that some such relation exists between pegmatite- and quartz-veins. But it must be strongly emphasized that the descriptions of such transitions should be fully proved by series of exact assays. This has not yet been done. It is possible, of course, that the vertical distance between pegmatites and normal gold-quartz veins may be so great that transitions between them could not ordinarily be studied in any one district; or it may be that, if some of the gold in quartz-veins has been derived by exhalations from a congealing magma, it was carried off by other agencies than the pegmatite-veins. Against the suggested relationship speaks the fact that California, Idaho and Oregon gold-quartz veins show no relation whatever to pegmatitic dikes; also, the conditions observed in North Carolina, where Pratt‖ describes normal auriferous quartz-veins, occurring together with barren lenses of pegmatitic quartz.

---

* *15th Ann. Rept. U. S. Geol. Sur.*, p. 678.

† *16th Ann. Rept. U. S. Geol. Sur.*, Part I., p. 687.

‡ *Amer. Geologist*, xix., p. 147.

§ *18th Ann. Rept. U. S. Geol. Sur.*, Part III., p. 312.

‖ *Mining and Metallurgy*, Feb. 15, 1901, p. 108.

The subject is attractive, and well worthy of further investigation.

NOTE.—Since this paper was written I have had opportunity to read Prof. Vogt's most interesting contribution, "Problems in the Geology of Ore-Deposits."* This, to a most desirable degree, confirms and completes the necessarily abbreviated statements in these notes, while its scope is very much larger. The pyritic deposits of the type Rio Tinto, Rammelsberg and Röros, which Prof. Vogt includes under the heading of contact-metamorphic origin, I have not attempted to discuss, on account of my very limited acquaintance with them.

The Deposits of Copper-Ores at Ducktown, Tenn.†

BY J. F. KEMP, NEW YORK CITY.

(Richmond Meeting, February, 1901.)

CONTENTS.

Introductory Description of Deposits of this Type.

ORE-BODIES of more or less lenticular shape and lying parallel with the foliation of schists and slates form a group of

---

* See page 125 of the present volume.

† This paper was practically prepared to be presented to the Institute at the New York meeting, February, 1899; but the pressure of entertainment and of other contributions prevented its delivery. It was my intention to illustrate it with specimens and lantern-slides. Until now, however, I have not been able to put it in shape for publication. Meantime, in the third edition of the "Ore-De-

well-marked types, world-wide in distribution, and recognized for many years. In some, the metallic mineral is magnetite or specular hematite; in others, some form of sulphide of iron is always accompanied by copper; and in still others, various metallic sulphides, often carrying gold, are sparsely scattered in a gangue of quartz. The second variety—that containing some form of the sulphide of iron, and known to the Germans as *Kieslager*—is the one which embraces the Ducktown deposits. In the greater number of instances ordinary pyrite, FeS_2, appears to be the chief mineral, with chalcopyrite as a very common and characteristic associate; but in important cases pyrrhotite (magnetic pyrites), Fe_7S_8, takes the place of the ordinary pyrite, and then forms the gangue of the copper-ore. For sulphuric acid fumes, ordinary pyrite (Fe 46.7, S 53.3) has the advantage over pyrrhotite (Fe 60.5, S 39.5) of 13.8 per cent. of sulphur, so that the latter is seldom employed for this purpose; but for copper-smelting there is small choice. Both varieties may occur in the same limited district, as at Ducktown, where the Isabella mine is reported to contain pyrite (the gossan only is now visible), while all the other claims, so far as known to the writer, carry pyrrhotite. One, the Burra-Burra, has both;—crystals of pyrite appearing in a matrix of pyrrhotite, like phenocrysts in a porphyry.

The other minerals in these deposits are much the same all over the world. Of metallic ores, zincblende and galena are almost always present in larger or smaller auxiliary amount, and may be quite abundant—the former then proving a serious drawback in the manufacture of sulphuric acid. A little silver is not at all uncommon, but other metals are so rare as to be negligible.

Of the silicates, garnet and actinolite, or some other variety of amphibole, are no doubt the commonest representatives;

---

posits of the United States," January, 1900, I have given a brief abstract of the conclusions which have been reached regarding the formation of the ores. My friend, Mr. W. H. Weed, of the U. S. Geological Survey, has presented to the Institute his valuable paper entitled "Types of Copper-Deposits in the Southern United States" (*Trans.*, xxx., 449), has treated of Ducktown, and has courteously quoted me. I wish to avoid repeating anything already stated by Mr. Weed, but I have necessarily referred to general geological features in order to be intelligible. The present paper deals more especially with the structure of the ore and the order of formation of the minerals.

but a considerable variety is known in one place and another, embracing biotite, epidote, pyroxene and others. At Ducktown, as will appear later, zoisite is a characteristic mineral, and it is known also at the Mons Petter mine, Sulitelma district, Norway. Quartz is, all things considered, the most common gangue-mineral, but calcite is likewise very widespread. Both appear at Ducktown. Occasionally, in foreign localities, there are minerals which indicate the action of fumarolic vapors, such as hydrofluoric acid, boracic acid and watery vapor. The resulting minerals are fluorite, tourmaline and chondrodite; but these are unknown, so far as the writer is aware, in America.

In shape these ore-bodies are more or less lenticular. The lense may be very long and relatively thin, or there may be a succession of lenses so as to simulate a bed. As a rule, the ore lies conformably to the foliation or schistosity of the wall-rock; and so general is this relation that among earlier observers, when schistosity and sedimentary bedding were esteemed synonymous, the belief was well-nigh universal that the sulphides were themselves a form of sedimentary deposit. Inasmuch, however, as we now know that schistosity is a product of dynamic metamorphism and shearing, and that it has no necessary connection with sedimentary bedding, although often parallel therewith, the relations of the sulphides to this feature of the walls cannot be interpreted without further proof as a case of interbedding. There certainly are instances in which the ore cuts the schistosity, as is shown by the drawings of Henrich* for the mines at Ducktown, where there is also abundant evidence of displacement since the ore was deposited.

Much has already been written which expresses the general features briefly outlined above. Von Groddeck, for example, in his invaluable *Lehre von den Lagerstätten der Erze*, makes a type, *Kieslager*, which is defined as follows (p. 112):

"Ore-beds, lenticular in shape, repeated and connected by zones like fahlbands. The essential ores are pyrite, chalcopyrite, and pyrrhotite, the latter usually carrying nickel. Sometimes one, sometimes the other of these ores prevail; but while the first two appear never to be absent, the last-named often fails. Galena, zincblende and other ores are, on the whole, subordinate."

---

* *Trans.*, xxv., 173.

Prof. J. H. L. Vogt has also discussed these ore-bodies at length* and has made many suggestions which will stimulate investigation, as is so often the case in his papers. W. H. Weed has more recently described Ducktown as the third of his "Types of Copper-Deposits in the Southern United States." He defines Ducktown veins as follows:†

"The third type is a pyrrhotite vein—a true fissure-vein the filling of which is essentially pyrrhotite or pyrite, almost barren of quartz, and represents the replacement of a zone of sheeted rock which was composed largely of metamorphic minerals."

These sulphide bodies in metamorphic schists and slates are quite widely distributed in America, being known and mined from Quebec to Alabama. Capelton, Quebec; Milan, N. H.; Richmond, Mass.; Ely, Vt.; the Arminius mine, Louisa co., Va.; the sulphide belt of Southwest Virginia; and Ducktown, Tenn., are the most important in the east.

In writing of Ducktown, I am anxious not to repeat in any way the paper by Carl Henrich already referred to, or the later one by W. H. Weed. Mr. Henrich had long and intimate connection with the mines, and excellent opportunities of observing significant but evanescent phenomena, which were exposed and then destroyed by breaking down the ore. But during a week's stay in June, 1898, I had the opportunity to become quite familiar with the mineralogy of the ores, especially through the courtesy of my friend, L. D. Huntoon, E.M., then in charge of the Mary mine. The only two shafts working at the time were the Mary and the Pittsburgh, and down both of these I had the privilege of going. Into the old black-copper workings of the London I also went, but as no other underground openings were accessible, I was forced to be content with studying the dumps of the remaining properties.

Topography of the Ducktown Region.

Even cursory examination of this region will show to any observer who has an eye for forms of topographical relief that

---

* *Ueber die Kieslagerstätten vom Typus Röros, Vigsnäs, Sulitelma in Norwegen, und Rammelsberg in Deutschland. Zeitschrift für Praktische Geologie*, Feb., April, May, 1894; and *Das Huelva-Kiesfeld in Süd-Spanien und dem angrenzenden Theile von Portugal, Idem*, July, 1899.

† *Trans.*, xxx., 452.

the veins outcrop in a series of hills, all of which rise to about the same level of 1700 feet above tide.* They therefore constitute the stumps of an old plain, now deeply scarred by renewed erosion. This would be called a peneplain in modern geographical phrase. (See Figs. 2 and 3.) Around the old plain, ranges of mountains, rising to still greater heights, close in the valley. All this was long since recognized by C. W. Hayes of the U. S. Geol. Survey, one of our keenest observers; and the Ducktown peneplain was identified with the base-level of Tertiary time. It is manifest that much material was removed in the waste of the land which produced this base-level; and it is possible that no small amount of vein-matter, now missing, contributed of its copper to form the black ores. The black ores must have successively migrated downward as the drainage-levels sank lower and lower, and established new horizons for the ground-water.

Geology and Petrography.

The country-rock is mica schist or quartz schist, usually of a pronounced and thinly foliated type. In several thin sections made from specimens gathered north of the Mary mine, from south of the Pittsburgh and Tennessee, and from the Burra-Burra ridge, little else than quartz and biotite, with an occasional garnet and some pyrrhotite, appears. (Fig. 4.) One more massive specimen, gathered south of the Pittsburgh Co.'s shaft, proved to contain quartz, actinolite, garnet and zoisite. (Fig. 5.) In my slides feldspar is almost entirely lacking. The schist is therefore regarded as a metamorphosed sediment. It was probably a slightly aluminous sandstone in some cases, and a more richly aluminous shale in others. Some evidence of eruptives was eagerly sought; but, except for certain masses of actinolite in the mines, more particularly the East Tennessee, nothing was seen that even suggested them, and the actinolite rock might quite as well be a metamorphosed calcareous bed. There are other changes in the mineralogy of the rocks near the veins, as will shortly appear. Throughout the country-

* Fig. 1 is reproduced from the Ellijay and Murphy quadrangles of the U. S. Geological Survey. The two sheets do not sharply correspond, and some adjustment of streams and roads has been necessary, on the line of juncture, about half an inch above the Georgia State boundary. The contours could not in all cases be brought together.

rock there is very little lime aside from that in the silicates; and the well-waters and springs are soft, and, so far as inorganic matter is concerned, singularly pure.

The schists sometimes contain more massive bands that are practically gneiss, and that may even simulate granite; but when thin sections have been prepared, they have revealed in all cases quartz and biotite, with only occasional and rare bits of feldspar. Except for the coarser foliation, the rocks are the same as the schists in all essentials.

Exposures are not very common, because a heavy mantle of residual soil covers almost all the surface. In this respect my impressions differ from those of Mr. Weed, who has described the exposures as rather abundant. The schists dip at a steep angle in the greater number of outcrops; and they display so little variety that in trips on horseback I could not satisfy myself regarding the relations of planes of bedding to schistosity in the steeply-dipping exposures. The schists contain not a few quartz veins; and the quartz is collected and used in the smelters to flux off the iron of the ores. While the time failed me before I could seriously attack the structural problems presented by the general geology, yet I felt that by a careful compilation of observations they could be solved, and that there was evidence of folding.

The schists are referred by Keith and Hayes of the U. S. Geol. Survey to the Ocoee series of pre-Cambrian age, as has been previously stated by Mr. Weed.

The metallic veins conform pretty closely, if not absolutely, to the schistosity; but as the wall-rock is seldom visible on the surface at the mines, the observation of the facts is not easy. In the open cut in the gossan at the Mary mine, Fig. 11, where iron-ore has been taken out, there appeared to be a discordance between the schistosity and the dip of the vein; but in such decomposed and crumpled rocks it is not easy to satisfy oneself.

The Mineralogy of the Ores and Gangue.

The ore is chiefly pyrrhotite, with very finely disseminated chalcopyrite. The latter is inextricably mingled with the former—to such a degree, in fact, as I have been informed, that when an experimental test was made in the attempt to concentrate the copper by magnetic methods, the heads and tails

assayed just the same. The pyrrhotite and chalcopyrite are massive and show no evidence of banding. All through their substance, however, one may detect dark blebs of quartz and spots of calcite. In thin sections, actinolite, garnet and zoisite can be distinguished (see Figs. 6, 7 and 8).

Premising this general statement, it will be in many respects advantageous to take up the minerals *seriatim*, beginning with those whose formation has clearly preceded that of the ore, continuing with the pyrrhotite, chalcopyrite and minor sulphides, and concluding with the still later species. The older ones are amphibole, pyroxene, garnet, and zoisite.

Minerals Older than the Ores.

Amphibole.—This is the most abundant of the silicates, and at the East Tennessee mine (now abandoned) seems to form a large part of the country-rock. The variety is pale green in thin section, and is doubtless actinolite. It forms interlaced rods and plumose aggregates. If one may judge from the lean material now remaining on the abandoned dumps, the ore consists of the sulphides disseminated through the actinolite. At the dumps of the other mines these aggregates of amphibole are common, although not so prominent as at the East Tennessee. Fig. 7 illustrates the relations of the actinolite to the sulphides, which have clearly been deposited among its broken fragments. Actinolite also occurs in all the massive ore in minute acicular crystals, which are shown in Fig. 6.

At the East Tennessee mine masses of talc may also be collected, which appear to have resulted from the alteration of the actinolite; but their relations to the ores have not been determined.

Pyroxene.—Diopside has not been observed in great quantity; but in a collection made for the Columbia School of Mines in 1894, by one of my old students, W. E. Clark, then connected with the Mary mine, there were two fine large crystals; and I have obtained some inferior ones since. By the eye alone it is easy to confuse this mineral with zoisite, and experience has convinced us that it is desirable to look critically at Ducktown specimens labeled zoisite in collections of minerals. Zoisite, however, fuses quite easily with intumescence before the blowpipe, while diopside fuses quietly. The diopside bears the

same relation to the ore as do the other silicates, and is clearly older.

Garnet.—Garnets occur in large, coarsely crystalline masses in the walls and leaner parts of the vein, and are widely distributed in small amount through the schists, and disseminated in the massive ore. (See Fig. 8.) I have one specimen in which they line a cavity in a mass of actinolite, and appear to be later than the latter. When they project into cavities they are beautifully crystallized and sometimes large. When met in diamond drill cores they have been esteemed a favorable sign as forerunners of an ore-body. A deep red variety is clear and fresh. A reddish-brown variety is also met, showing perfect luster on its beautifully developed crystal-planes, but consisting, inside of a mere skin of garnet, of a central mass of calcite, with little veinlets of sulphides along all the cracks. One extremely interesting feature of the garnets is the presence of the hexoctahedron, $\frac{3}{2}O3$, as determined by my colleague, Prof. A. J. Moses. In some specimens the hexoctahedral faces are almost as large and prominent as are those of the usual tetragonal trisoctahedron and rhombic dodecahedron. The garnets are stated by Professor Moses to resemble strongly the essonite of Ala, in Piedmont; and he has remarked a similar variety associated with vesuvianite, at the Raymond mine in Maine. The massive garnet is greatly shattered and cracked, and only the freely projecting crystals in the vugs have escaped the force of geological disturbances. Repeated observations prove that the ores have entered the cracks at a later period, and that they have even enveloped fragments of garnet in their mass. In the cases of the garnet crystals, whose garnet substance is only about a millimeter thick, and whose interior is practically all calcite, it would seem unquestionable that the former has been replaced by the latter. Garnet is well known to be the most hospitable of minerals to foreign guests, but it could not have forced the overwhelming amount of calcite to assume its shape. At the same time it is surprising that the replacement stopped just short of completeness and left the crystal form unharmed. A similar case of orthoclase and tourmaline (the latter outside) has been described by E. H. Williams, Jr.* Calcite also occurs, mantling the garnet crystals.

* *Amer. Jour. Sci.*, iii., xi. (1876), 273; xl. (1890), 63.

Zoisite.—Zoisite has been long known as one of the interesting minerals of the district. It is not infrequently found in the schists as small, detached fragments of crystals, but it reaches very considerable abundance at times in the veins, especially at the Mary mine. It forms prismatic aggregates, which are often bent or fractured, but the wounds and fissures of which have been filled with infiltrated sulphides. Fig. 10 is reproduced from a photograph of such a specimen, the crystals being about eight inches long. Terminal crystal-planes are rare, but they have been recorded, and are depicted in Dana's *Treatise on Mineralogy*.

The zoisite from Ducktown was analyzed nearly forty years ago by Genth and Trippel, and again twenty years later by Sipöcz, with the appended results:

Analyst.	SiO_2. Per cent.	Al_2O_3. Per cent.	Fe_2O_3. Per cent.	FeO. Per cent.	MgO. Per cent.	CaO. Per cent.	H_2O. Per cent.	MnO. Per cent.	CuO. Per cent.	Total. Per cent.
1. F. A. Genth, .	40.04	30.63	2.28		trace	25.11	0.71	0.19	0.24	99.20
2. Alex. Trippel, .	43.20	29.60	2.88		0.56	22.72	0.26			99.22
3. " " .		29.08	2.73		0.60	23.93	0.26			
4. Sipöcz, . .	39.61	32.89	0.91	0.71	0.14	24.50	2.12			100.88

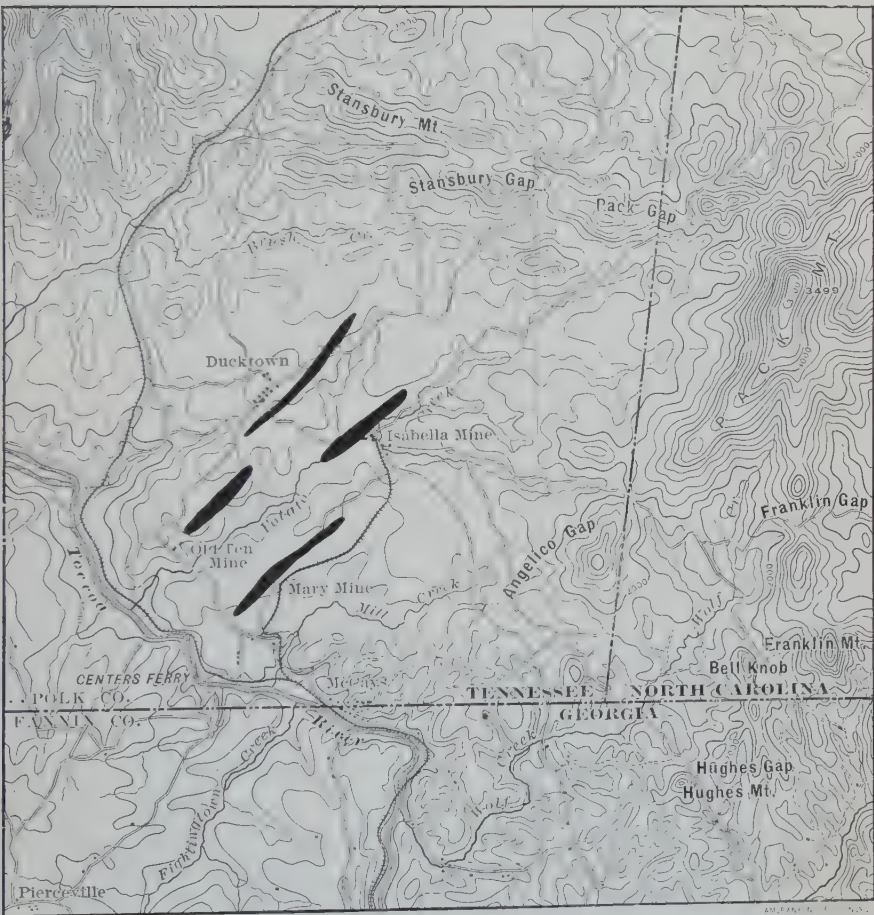
Nos. 1, 2 and 3 are from F. A. Genth's "Contribution to Mineralogy," *Amer. Jour. Sci.*, March, 1862, p. 197. No. 1 is by Genth, No. 2 by Alex. Trippel, the silicate being broken up by fusion. No. 3 is also by Trippel, but the silicate was decomposed by hydrofluoric acid. In No. 3 traces of potash were recorded. No. 4 is by Sipöcz, *Sitzungsberichte der Akademie der Wissenschaften*, Vienna, lxxxii., (1), 141. 1880.

Zoisite has the theoretical formula H_2O, $4CaO$, $3Al_2O_3$, $6SiO_2$, and is thus practically a lime-alumina silicate. It differs from epidote in that the latter has a large part of the Al_2O_3 replaced by Fe_2O_3, and is monoclinic, as against the orthorhombic crystallization of the former.

The amount of Fe_2O_3 in the Ducktown zoisite, as shown by the above analyses, is comparatively small. Zoisites are known which carry more than 6 per cent. of Fe_2O_3. Essonite, it may be remarked, is a variety of grossularite, the lime-alumina garnet, the theoretical formula of which is $3CaO$, Al_2O_3, $3SiO_2$; but, so far as the writer is aware, no analyses of Ducktown specimens have been made.

In its characteristic associations zoisite is found in the metamorphic schists that have been derived either from some calcareous form of sediment or from some eruptive rock relatively

FIG. 1.



Topographic Map of the Vicinity of Ducktown, Tenn. Reproduced from the Ellijay and Murphy quadrangles of the U. S. Geographical Survey. The heavy black bands are the outcrops of ore.

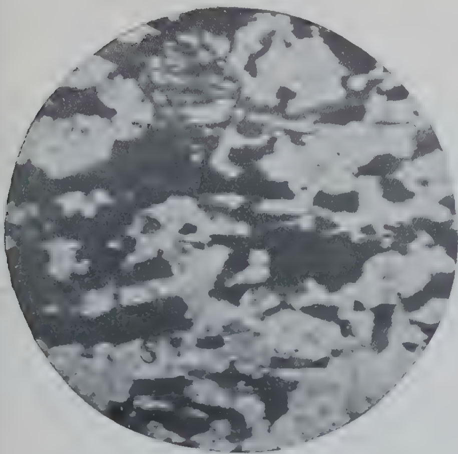
Fig. 2.

Panorama of the Ducktown Plateau or Peneplain. This picture, taken from the club-house, a mile N.E. of the Isabella mine, and looking W., brings out the sky-line and the trenching produced by the streams. Potato Creek is at the left, beyond the field of view.

Fig. 3.

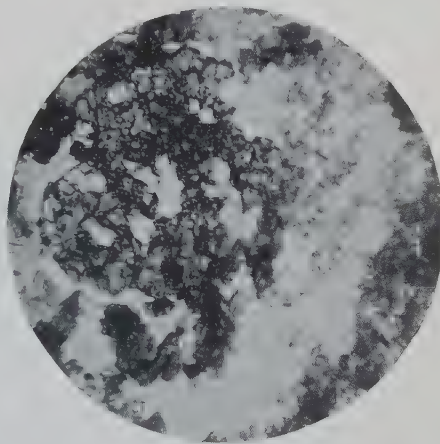
View looking Southwest down Potato Creek. The broad valley of the creek is shown, with the trenched plateau on each side, and the smelting-works of the Ducktown Copper, Sulphur and Iron Co. (about a mile distant).

FIG. 4.



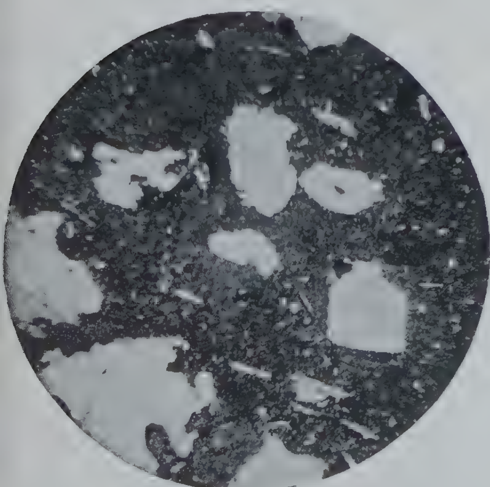
Photomicrograph of Mica Schist. The mineral near the top, showing strong relief, is garnet. The white mineral is quartz, and the dark, biotite. (Magnified 17.3 diameters.)

FIG. 5.



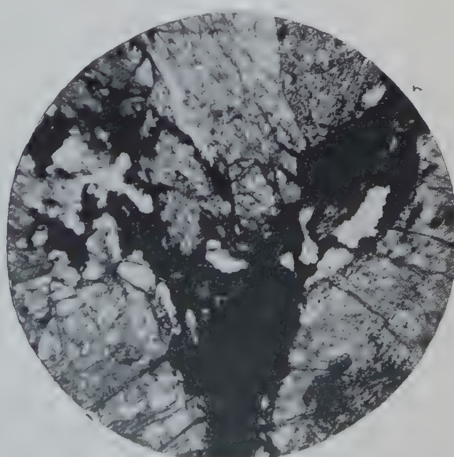
Photomicrograph of Hornblendic Schist. The mineral on the left with strong relief is garnet. The mineral in the center with fairly strong relief is zoisite. The white mineral is quartz, and the dark is actinolite. (Magnified 17.3 diameters.)

FIG. 6.



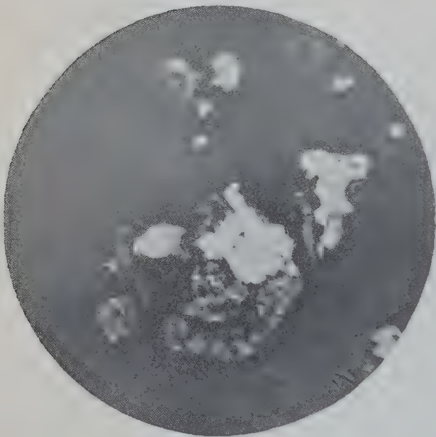
Photomicrograph of the Ore of the Mary Mine. The clear, white, angular mineral is quartz. The irregular white mineral above the center and vertically banded, is calcite. Three large calcites are in the lower left-hand field. The small, white rods are actinolite. The mottled background is pyrrhotite and chalcopyrite. (Magnified 40 diameters.)

FIG. 7.



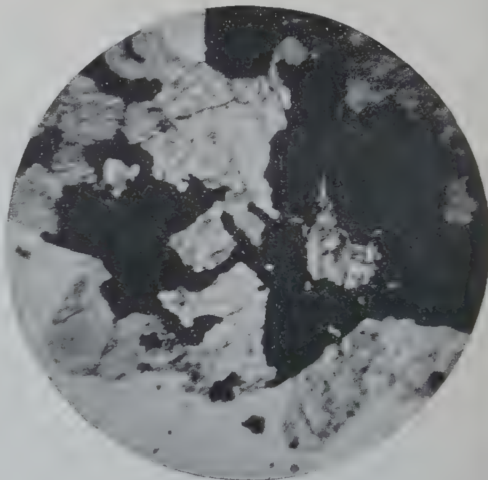
Photomicrograph of Ore from the East Tennessee Mine. The white mineral is actinolite. The dark mineral is chalcopyrite, which has filled even minute cracks in the shattered actinolite and has replaced it when crushed and altered. (Magnified 17.3 diameters.)

Fig. 8.



Photomicrograph of the Ore of the Mary Mine. The clear, white mineral is quartz. The large, broken mineral below the center, with high relief, is garnet. The little rods are actinolite. The background is pyrrhotite and chalcopyrite. (Magnified 36 diameters.)

Fig. 9.



Photomicrograph of Ore from the East Tennessee Mine. The white mineral is calcite. The dark mineral is chalcopyrite which has entered cracks and fissures in the calcite. (Magnified 40 diameters.)

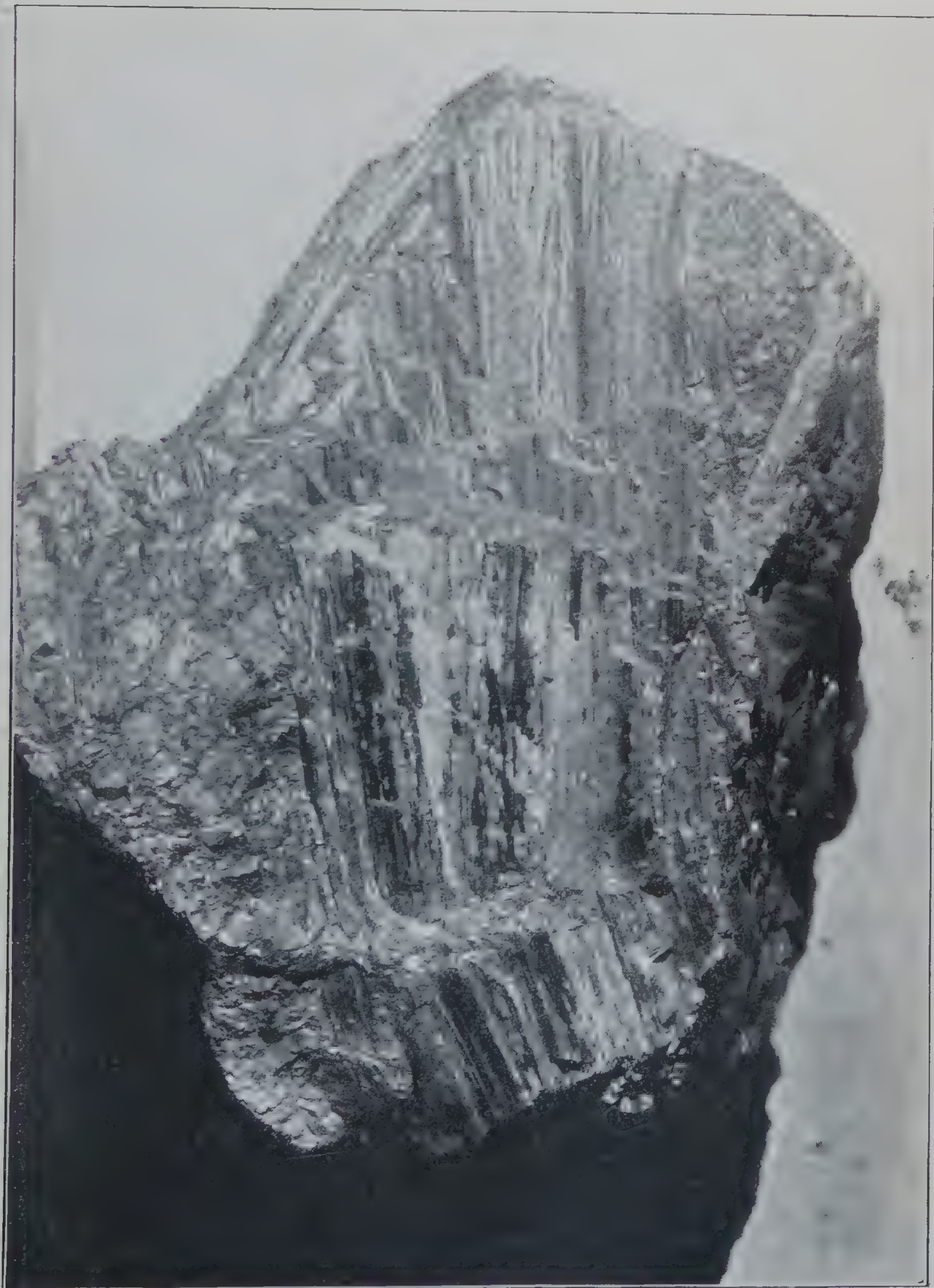
rich in lime, such as gabbro. An aluminous, siliceous limestone or a calcareous shale might easily yield it, and probably has done so in the present case. In the metamorphic derivatives of the gabbros it is the basic lime-soda feldspar that yields it, but there is very slight if any evidence that these rocks ever existed at the Ducktown mines.*

Calcite.—There is evidence that at least a large part of the calcite of the veins entered before the ores. In the replaced garnets, the calcite contains the sulphides in minute stringers, which have evidently been introduced along cracks. Fig. 9 is from a photomicrograph of a specimen of East Tennessee ore, and shows the pyrrhotite and chalcopyrite permeating the little fissures between the grains of calcite.

Again, the calcite is found in scattered and small bits in the massive ore, as shown in Fig. 6. It gives the impression then of having filled cavities in the ore. It is not at all improbable that so soluble a mineral has had several periods of formation.

* In the discussion of this paper at the Richmond meeting, C. W. Hayes stated that gabbros outcropped extensively a few miles north of Ducktown.

FIG. 10.



Specimen of Prismatic Zoisite, Broken near the Bottom by Geologic Movements and Re-cemented with Pyrrhotite and Chalcopyrite. Actual size.

FIG. 11.

Open Cut left by Iron-Ore Mining in the Gossan of the Mary Mine. (June, 1898.)

FIG. 12.

Roasters of the Ducktown Copper, Sulphur and Iron Co. (June, 1898.)

Quartz.—Quartz is the most abundant mineral in the wall-rocks, and it is possible that some of the included bits in the massive ore may be residues of crushed rock and may antedate the ore. Others that have been observed in the thin section associated with calcite, as illustrated in Fig. 8, are probably later infiltrations. Much quartz is of this nature, as will be demonstrated later.

Apatite.—One small, hexagonal crystal of apatite has been observed in a specimen of ore, rich in diopside.

Rutile.—In thin sections of the ore a dark brown mineral can occasionally be detected in irregular bits and masses. After much search an individual was found which afforded a positive, uniaxial interference figure, and therefore the mineral is considered to be rutile. It is a minor constituent, but quite widely distributed, being included in the sulphides precisely as are the bits of garnet, zoisite and amphibole.

In summary, it may be said that amphibole, pyroxene, garnet, zoisite, some calcite, and perhaps some quartz, apatite and rutile, are older than the ores.

The Ores.

The group of the older sulphides embraces pyrite, pyrrhotite, chalcopyrite, and small amounts of zincblende and galena.

Pyrite.—Pyrite is not extensively exposed in the mines now in operation. In the ore of the Burra-Burra, however, it is prominent. Moderately large and fairly well-developed crystals of the general shape of the cube and pentagonal dodecahedron are buried in a matrix of pyrrhotite and chalcopyrite, which latter are moulded around them. It would appear, therefore, that the pyrite is older than the others. Irregular but small masses have also been noted in the Mary ore, but they throw no light on the paragenesis.

Zincblende.—This mineral appears in minor amount at the Mary mine, and possibly elsewhere. It favors the coarsely crystalline aggregates of garnet, zoisite or other silicates, and, with the galena, is probably older than the pyrrhotite and chalcopyrite. It is a dark brown variety. The note on rahtite, in the review of the minerals of the gossan (p. 265) will be of interest in this connection.

Galena.—Galena is somewhat rare, but is occasionally met in the same relations as zincblende. It is involved in the other sulphides; but by careful search one specimen has been found into which the chalcopyrite and pyrrhotite have entered, and have then been precipitated on the cleavage and other cracks. In this connection attention may be directed to harrisite, as cited under the minerals of the gossan. There is some evidence that both the zincblende and the galena had a later period of minor formation at the time of the precipitation of the quartz veins. Zincblende, at least, occurs buried in the clear, vitreous quartz.

Pyrrhotite.—Pyrrhotite is the most abundant of the metallic minerals, and constitutes the greater portion of the ore-bodies. Cross-sections many square yards in area are often exposed, which consist chiefly of it. There is some evidence that it came in before the chalcopyrite, because the latter, in some specimens, runs through it in small veinlets and little stringers. The chalcopyrite also favors the neighborhood of the quartz and calcite, that are distributed throughout the ore, and that appear to have filled cavities. Still the evidence is obscure; and it is possible that pyrrhotite and chalcopyrite came in together, although my disposition is to believe the chalcopyrite to be the later of the two.

As distinct from the massive and fine-grained pyrrhotite of the usual ore, there is a coarsely-crystalline variety, that has apparently been formed at the same time with the later quartz veins, of which mention will be shortly made. It can be found in the Mary mine as rude, tabular crystals, showing faint rhombohedrons, but so near a disk in shape as to prevent accurate determinations. The disks are wholly enclosed in the quartz, and belong to a late and relatively unimportant generation.

Chalcopyrite.—It has been necessary to refer to this mineral so fully in speaking of the pyrrhotite that little remains to be said. It is closely involved with the pyrrhotite in almost all cases: but it may be found alone, in amount sufficient to yield hand-specimens, and is also disseminated by itself in the silicates.

It is interesting to note, in this connection, that E. Weinschenk reaches the same conclusions as to the order of forma-

tion of the sulphides in his description of the very similar ore-body at Silberberg, near Bodenmais, Bavaria,* but the view advanced for Silberberg, that the ore has entered in a molten condition, would not apply at Ducktown.

Later Minerals, not Belonging to the Gossan.

Quartz.—At some period after the ore-bodies had been essentially completed, disturbances produced cracks, which became filled with veins of clear, transparent quartz. Henrich describes them as forming nearly horizontal floors across the ore, and as serving to limit the progress of the gossan to some extent. I have not seen them in place, but have obtained specimens on the dumps. The quartz is beautifully clear, and contains the later zincblende and pyrrhotite described above. It is probable that some of the small bits of quartz enclosed in the ore also came in at this stage, and that some calcite was likewise introduced. Some specimens of the quartz have been collected which are etched in a really striking manner, and which present peculiar pits that are being studied by Prof. A. J. Moses. They indicate further circulations after the formation of the quartz veins had ceased, but of the composition of these solutions we can only speculate.

Graphite.—Graphite, or some closely related carbon mineral, is met in occasional specimens of the ore of the Mary mine. It appears to specially favor the crushed masses, and was probably of late introduction. It not only forms fine leaf-like aggregates, but in thin sections may be detected by the microscope as minute spheroids in the midst of other minerals, such as calcite and chalcopyrite.

It must have been introduced as some gaseous or very mobile liquid hydrocarbon, which has penetrated into minute cavities and filled larger cracks, and has been subsequently changed to graphite. It is interesting to note, in this connection, that some cyanogen compounds yield graphite readily under conditions which are by no means extraordinary, and which are reached at moderate temperatures. In the general discussion of the origin of graphite in an extended series of recent papers, E.

---

* "Der Silberberg bei Bodenmais im Bayerischen Wald."—*Zeitschrift für praktische Geologie*, March, 1900.

Weinschenk, of Munich, has laid much emphasis on the importance of cyanogen compounds.

The Formation of the Ore.

From the above facts it is evident that after the silicates, amphibole, garnet, zoisite and diopside, had been produced—probably by the metamorphism of some calcareous original—there was faulting, or at least movement and crushing, where we now find the ores. The movements took place where the country-rock appears to have been specially rich in lime. Into this crushed and presumably more or less open-textured material came the solutions bearing the metallic minerals. In the Burra-Burra ground, pyrite was first deposited, and later pyrrhotite and chalcopyrite. Elsewhere pyrrhotite and chalcopyrite were introduced, the latter probably later and after an intermediate movement of the walls.

The sulphides insinuated themselves into the broken silicates, and penetrated as well into the schists at considerable distances from the veins. Mr. Weed has urged that the ore replaced the rock in the case of the large ore-bodies, which have few silicates now in them, and indeed in the veins in general. I have reflected somewhat as to the original rock that was replaced, and have sought for evidence. As the photomicrographs show in part, and as abundant observations prove, the sulphides abut sharply against perfectly fresh specimens of all the silicates cited, of calcite, and of quartz. There is no sign of chemical reaction; but in a slide of East Tennessee ore I found the sulphides between large pieces of actinolite and in veinlets, which elsewhere were composed of comminuted and decomposed silicates. (See Fig. 7.) It therefore seems probable that the replaced material consisted of the crushed and greatly comminuted country-rock, which in this condition would prove an easier prey to the ore-bearing solutions. Where the crushing was most severe, the large ore-bodies are found. Unless some factor of this sort exercised an influence, it seems strange that the process of replacement should cease so sharply against perfectly fresh and unchanged representatives of the presumably replaced minerals. Otherwise, as is so often the case in mineral veins, and as is so well

described by Lindgren in his recent paper,* some attendant alteration should be manifested in the wall-rocks.

Another supposition which deserves consideration is, that some other mineral, not a silicate, has been replaced. If so, it must have been one in which garnet, actinolite and zoisite existed as contained minerals, so that when the ore completed the replacement they were enveloped. Calcite would be the most natural one to fill these requirements, and it is possible that it so existed in the form of a bed of limestone. We find, indeed, sulphides now in the midst of calcite at the East Tennessee mine, as illustrated in Fig. 9; and the supposition would not be incompatible with observed facts. On this supposition, it is, however, remarkable that we do not observe, as Mr. Weed has suggested, more of the limestone on the strike of the veins. That veins of the enormous cross-sections here exhibited were deposited in open cavities, seems to me incredible.

A third supposition, which should be mentioned, and which is suggested by the observed facts of the genesis of zoisite elsewhere, is that there once existed a dike of gabbro where the ore now is. This dike must have had its feldspar changed to zoisite, calcite and garnet, and its pyroxene to actinolite by metamorphism or other alteration. The sulphides then entered and so largely replaced it with ore as to mask its original characters. I find, however, so little to support this hypothesis that it seems far less probable than the one which is based on original calcareous sediments.

The Gossan Minerals.

When the ore-bodies had been finally produced, and when they became placed above the level of the ground-water, oxidation and the production of gossan minerals began. It is quite probable that a very great vertical extent of former vein-matter was in this way affected; and it is reasonable to suppose, according to abundant experience in other districts, that the copper migrated downward, and was either deposited at or near the water-line, or else, as Mr. Weed† has so ably set forth in his recent papers, it penetrated below the ordinary water-level

---

* "Metasomatic Processes in Fissure-Veins," *Trans.*, xxx., 578.

† W. H. Weed, "Enrichment of Mineral Veins by Later Metallic Sulphides," *Bulletin Geological Society of America*, xi., 179–206, April, 1900.

and enriched lower-lying and leaner ores. I do not find much evidence of the latter change; as the copper-bearing mineral of the unaltered veins is, so far as known, entirely chalcopyrite and not the enriched sulphides.

At or near the water-level the black ores were found which were formerly supposed to be largely the black oxide, melaconite, but which Mr. Weed has determined to be chalcocite. A number of other minerals, and some bad species, have been described from these surroundings, of which a list is here appended. There seems to have been little that is exceptional or worthy of remark, in the development of the gossan, which has not been already covered by Mr. Weed in 1900 and J. D. Whitney in 1855. (See *Bibliography* below.)

Alisonite, a variety of covellite, rich in lead, and probably formed by a partial replacement of galena. The mineral is mentioned in Dana's *Mineralogy* among those found at Ducktown.

Allophane,—amorphous, hydrated silicate of alumina.

Azurite and *Malachite*, not specially abundant.

Copper, in the native form.

Cuprite, var. *chalcotrichite*, is reported by Shepard.

Bornite is present in small veinlets in a specimen of quartz from the Mary mine. The quartz, now much shattered, appears to be a pseudomorph after some coarsely crystalline mineral, whose shape suggests orthoclase.

Ducktownite is probably a mixture of pyrite and chalcocite. The name was given by C. U. Shepard, 1859, in a report on the Mt. Pisgah copper-mine, near Ducktown. A number of other worthless names of minerals from Ducktown appear in the report. (See *Amer. Jour. Sci.*, July, 1859, p. 129.)

Harrisite, a pseudomorph of chalcocite after galena, named by C. U. Shepard in 1855, in a report on the Canton mine. (Chester's *Dictionary of Mineral Names.*)

Limonite forms great masses overlying the black ores and the sulphides. It is mined at the Isabella and sold to furnaces in the Chattanooga region. It is in crusts, stalactites, pipes, pots, and all the usual shapes of this mineral, and is often beautifully iridescent. It contains a small amount of copper, reported to be one per cent. and less.

Melaconite is reported in the older papers; but it may have been chalcocite, as indicated by W. H. Weed.

Melanterite, or natural copperas, the hydrated sulphate of iron.

Rahtite, supposed by C. U. Shepard to be a new mineral, is probably a massive blende, contaminated with other minerals containing copper and iron. It was named for Capt. Raht, one of the early mine-managers, and came from the gossan. (*Amer. Jour. Sci.*, March, 1866, p. 209.)

Sulphur appears in the gossan in small flakes.

The metallurgical treatment of the ore is described by Mr. Henrich in the paper cited below. A view of the roasters of the Ducktown Copper, Sulphur and Iron Co. is given in Fig. 12, which likewise illustrates one of the broad creek bottoms.

Bibliography.

W. M. Brewer. "Ducktown Copper-Mining District." *Eng. and Min. Jour.*, March 23, 271 (1895).

Carl Henrich. "The Ducktown Deposits and the Treatment of the Ducktown Ores." *Trans.*, xxv., 173.

J. L. Kleinschmidt. *Gangstudien*, iii., 256, 1856.

A. Trippel and H. Credner. Report on the Ducktown Region to the American Bureau of Mines, 1866.

M. Tuomey. "A Brief Notice of Some Facts Connected with the Ducktown Copper-Mines." *Amer. Jour. Sci.*, March, 1855, 181.

W. H. Weed. "Types of Copper-Deposits in the Southern United States." *Trans.*, xxx., 449.

A. F. Wendt. "The Pyrites-Deposits of the Alleghanies." *School of Mines Quarterly*, vii., 1866. *Eng. and Min. Jour.*, June 5–July 10, 1886.

J. D. Whitney. "Remarks, etc., with reference to East Tennessee Copper Mines." *Amer. Jour. Sci.*, July, 1855, 53.

Problems in Hauling and Hoisting.

BY ALEXANDER BOWIE, GALLUP, N. M.

(Richmond Meeting, February, 1901.)

Of the following problems, some have been suggested by recent articles in technical journals, which have led me to believe that the mathematical discussion here submitted may be of use to mining engineers.

Problem I.

To Find the Grade or Angle of Inclination upon which the Power Required to Move a Loaded Car Down-hill Will Haul an Empty One Up-hill.

Let a be the desired angle of inclination; C, the coefficient of friction; W and w, the weight in pounds of the loaded and of the empty car, respectively.

When a car W is placed on an inclined plane, the force with which it tends to move down the plane (disregarding friction) is

$$(1) \qquad W \sin a.$$

The pressure perpendicular to plane of a car W resting on an inclined plane is

$$(2) \qquad W \cos a,$$

and as the amount of friction in any case equals pressure multiplied by coefficient of friction, the amount of friction encountered in moving a car W on an inclined plane is

$$(3) \qquad WC \cos a.$$

Hence, when the force with which the car tends to move downhill is exactly held in equilibrium by the amount of friction,

$$(4) \qquad W \sin a = WC \cos a, \text{ or } \frac{\sin a}{\cos a} = \tan a = C.$$

That is, the coefficient of friction is equal to the tangent of the angle of inclination on which the force exerted by gravity is exactly counterbalanced by the frictional resistance. This angle is known as the angle of friction, the angle of repose, or the limiting angle of frictional stability.

When the angle of inclination of a plane is equal to the angle of friction, the smallest force applied to a car W (resting on it) in a direction parallel to and down the plane, will move the car down the plane. When the angle of inclination of the plane is less than the angle of friction, the force with which the car opposes motion down the plane will be

$$(5) \qquad WC \cos a - W \sin a,$$

and when the angle is greater than the angle of friction, the force required to prevent the car from moving down the plane (or its tendency of motion down the plane) will be

$$(6) \qquad W \sin a - WC \cos a.$$

When it is desired to move the car up the plane, whether the angle of inclination is greater or less, or equal to the angle of

friction, the force with which the car will resist motion up the plane will be

$$(7) \qquad W \sin a + WC \cos a,$$

in which expression we substitute w for W when an empty car is in question. To find the angle of inclination at which the force with which an empty car resists motion up the plane is exactly equal to the force with which a loaded car resists motion down the plane, we equate expressions (5) and (7) and obtain

$$(8) \qquad CW \cos a - W \sin a = w \sin a + Cw \cos a,$$

whence,

$$(9) \qquad \frac{C\,(W-w)}{W+w} = \frac{\sin a}{\cos a} = \tan a,$$

or the tangent of the required angle of inclination. If $W = w$, this formula gives zero as the tangent; that is to say, under these conditions, the required grade is level.

If we suppose W and C to remain constant, while w decreases from $w = W$, gradually passing through all possible values until it reaches 0 (at which limit the formula reduces to $C = \tan a$), the tangent of the angle of inclination will pass through all possible values between 0 and C; consequently the angle of grade required will always be found between 0 and the angle of friction, whatever be the relative weights of the loaded and the empty car. It is obvious that the greater the difference between these weights the nearer will be the required grade to the angle of friction; and, the smaller this difference, the nearer will be the required grade to a dead level. And, as the grade varies directly with the coefficient of friction, it is obvious that the smaller that factor can be made, the less the grade will be.

Problem II.

To Find the Minimum Angle of Inclination for a Self-Acting Gravity-Plane on a Straight Line and of Uniform Grade.

It is evident that the required angle of inclination must be greater than the angle of frictional stability.

The force with which the loaded car tends to move down the

plane when the angle of inclination exceeds the angle of friction is

$$(10) \qquad W \sin a - CW \cos a. \qquad \text{(See 6.)}$$

Under the same conditions the force with which the empty car resists motion up the hill is

$$(11) \qquad w \sin a + w\, C \cos a. \qquad \text{(See 7.)}$$

It is desired to find such an angle of inclination that these two forces will be exactly equal to each other; therefore, equating the expressions that represent the two forces, we have

$$(12) \quad W \sin a - CW \cos a = w \sin a + C\, w \cos a.$$

Transposing and dividing, we have

$$(13) \qquad \frac{(W + w)\, C}{W - w} = \frac{\sin a}{\cos a} = \tan a,$$

or the tangent of the required angle. Assuming that the loaded and empty cars are connected by means of a rope passing around a sheave or cylinder-drum at the top of the plane, and that this connection itself has neither weight nor friction, the angle found by (13) may be called the minimum angle of inclination for a self-acting incline of uniform grade. On this slope, the opposing forces of the loaded and empty cars will be balanced in such a way that (apart from the weight and friction of the connecting-rope and gear) the slightest increase in the angle will make the plane a self-acting one, or the slightest force applied to the loaded car in a direction down the plane, or to the empty car up the plane, will create motion.

If we suppose $W = w$ in (13), the equation reduces to $\frac{(W + w)C}{0} = \infty$; or the tangent of 90°. That is to say, when both the ascending and the descending weights are equal, the position of the plane is vertical.

If W and w receive each a coefficient n, representing any number greater or less than unity, we have from (13)

$$(14) \qquad \frac{n(W + w)C}{n(W - w)} = \tan a;$$

which does not change the value of the tangent. Consequently, an incline that cannot be worked as a gravity-plane with a one-car trip cannot be so operated with two or more cars to a trip.

When $W = w$, if we suppose W and C to remain constant, and w to decrease, gradually passing through all possible values until it reaches zero, when it reaches that limit $\frac{W+w}{W-w} = 1$ and equation (13) reduces to $\frac{(W+0)C}{W-0} = \tan a$, or $C =$ tangent of angle of friction. Consequently, while w is passing through all possible values between 0 and W, the tangent of the angle of inclination will pass through all possible values between C (the tangent of the angle of friction) and infinity (the tangent of 90°); therefore, the smaller the difference between W and w, the greater the angle of slope required to make a self-acting plane; and, conversely, the greater the difference between W and w, the smaller the angle of slope required. But whatever relation the weight of the empty car bears to the weight of the loaded car, the required angle will be found between the limits of the angle of friction and 90°.

In the discussion of this problem, thus far, the weight of the rope and its friction on the incline-rollers and the friction of the periphery and the axle of the drum or sheave around which it passes, have not been taken into consideration. As to this part of the problem, it is evident at once that the loaded car, when starting from the top of the incline, will have a rope as long as the incline to drag up the plane, together with the empty car attached to the end of it. The principal factors in determining the coefficient of friction for wheeled carriages moving on rails are the ratio of the diameter of the wheel to that of the axle; the quality of the lubricant; and the smoothness of the contact-surfaces. If we suppose that the ratio of the diameter of the incline-roller to its axle-diameter is the same as that of the wheel to its axle, and that the smoothness and lubrication are the same in both cases, then the coefficient of friction for a rope borne on such rollers will be nearly the same as that found for the pit-cars. If the rope were rigid and the surfaces of the rope and sheaves were as smooth as those of the rail and the wheel, the coefficient of friction ought to be the same in both cases; but by reason of the sag of the rope

and the roughness of the surfaces it is possible that the coefficient of friction for the rope ought to be a little greater than for the car. The difference, however, would be so slight that no material error will be made in assuming them to be the same. We will assume, therefore, that the gravity and frictional resistance which the rope offers to motion up the plane are determined in the same manner as those for the pit-car. The resistance offered by the rope will be continually decreasing as the empty car ascends the plane; when the cars are half way on the plane the rope ought to balance itself; when the loaded car passes that point it is relieved of any resistance due to the rope; and thereafter the increasing weight of rope on the loaded side assists in pulling up the empty car. But when the empty car starts up from the foot of the plane, the resistance offered by the rope and empty car will be the gravity and friction due to the weight of the car plus the weight of a rope of the required size and as long as the incline. Let r be the weight in pounds of a suitable rope of the length of the incline. Adding this to the weight of the empty car in (12) we have

(14) $\mathrm{W} \sin a - \mathrm{CW} \cos a = (w + r) \sin a + \mathrm{C}(w + r) \cos a$;
whence,

$$(\mathrm{W} - (w + r)) \sin a = \mathrm{C}\,(\mathrm{W} + w + r) \cos a; \text{ or}$$

$$\frac{\sin a}{\cos a} = \tan a = \frac{\mathrm{C}\,(\mathrm{W} + w + r)}{\mathrm{W} - (w + r)}, \tag{15}$$

which gives the tangent of the minimum angle for a self-acting plane under the conditions assumed.

If we now assume that the values of W, w and C are constant (w being, of course, always smaller than W), and that the value of r gradually increases from zero, *i.e.*, from $(w + r) = w$, to $w + r = \mathrm{W}$, formula (15) will give, for the tangent of the required angle, a fraction with the denominator $\mathrm{W} - \mathrm{W}$, or zero: that is, the angle will be $90°$; whereas, for $r = 0$, we shall have, as the tangent of the required angle, $\frac{\mathrm{C}(\mathrm{W} + w)}{\mathrm{W} - w}$. Between these two limits will lie the required angles of the plane for all intermediate values of r.

Assuming that the rope has a uniform weight per linear unit, it is evident that the required angle of inclination will in-

crease with the length of the rope (with the length of the incline, which is here the same thing), and that when $w + r = W$ the maximum limit is reached for a self-acting plane of uniform grade, with common sheave or cylindrical drum. To be more exact: so long as $W \sin a > (w + r) \sin a + C (W + w + r) \cos a$, the conditions permit a self-acting plane; but when $W \sin a$ is equal to, or smaller than, the second member of this formula, no motion can be produced in the system by gravity alone.

If W and w receive each a coefficient n, representing any number greater or less than unity, r must receive practically the same coefficient, because the weights of steel ropes are nearly in proportion to their respective safe working-strengths, and therefore, if we increase the load, we must increase in the same ratio the weight of the rope. Formula (15) would thus receive the same coefficient in numerator and denominator; in other words, the tangent sought would be the same for any number of cars per trip as for one car.

If the value of r be assumed to be constant, while W and w are varied by any coefficient n, the fraction in formula (15) would become $\frac{nC (W + w) + Cr}{n (W - w) - r}$; that is, the required tangent would decrease with the increase, and increase with the decrease, of n. In other words, if the rope used for one-car trips be stronger than necessary, so that additional cars can be put on without using a heavier rope, then it may be possible to make the plane self-acting by simply increasing the number of cars in a trip, without changing any other factors of the problem.

To find the value of n under this supposition, when r and the angle of inclination are constants. In (15) let S be substituted for $W + w$; D for $W - w$; and q for $\frac{\tan a}{C}$. We then have equation (15) under the form $\frac{n S + r}{n D - r} = q$, from which we readily obtain $n = \frac{r (1 + q)}{D q - S}$.

The above discussion of equation (12) and the formulas derived from it shows that the tangent of the minimum angle of inclination for a gravity-plane:

1. Must be greater than that of the angle of wheel-friction;
2. Varies directly with the coefficient of wheel-friction;
3. Varies directly with the quotient obtained by dividing the aggregate weight of the loaded car, the empty car, and the rope by the weight of the loaded car, minus that of the empty car and the rope.
4. Is the same for any number of cars as for one car, when the safe working-strength (and therefore the weight) of the steel rope is commensurate with the load.

In this discussion, the friction on the periphery and axle of the drum or sheave has not been considered. The amount of resistance due to this cause will be measured by the strain, multiplied by the proper coefficient of friction, as found for the drum or sheave. The resistance of the empty car and rope to motion up the plane is, according to (7), with the substitution of w for W, and the introduction of r,

$$(w + r) \sin a + C (w + r) \cos a; \tag{16}$$

and the strain exerted by the loaded car to move down must be at least equal to this; hence the strain on the drum or sheave around which the connecting-rope passes must be at least

$$2\ [(w + r) \sin a + C (w + r) \cos a];$$

and if C′ be the coefficient of friction for the drum or sheave, and f be the amount of resistance due to this cause, then

$$f = 2C'\ [(w + r) \sin a + C (w + r) \cos a]. \tag{17}$$

Equating the motive power to the sum total of resistances, we have

$$W \sin a = CW \cos a + (w + r) \sin a + C (w + r) \cos a + f, \tag{18}$$

from which we finally obtain

$$\frac{C (W + w + r) \times \dfrac{f}{\cos a}}{W - (w + r)} = \tag{19}$$

tangent of angle for minimum grade of self-acting gravity-incline when all resistances of gravity and friction are considered.

In view of the discussion of equation (12), and the formulas

derived therefrom, it becomes evident that if the conditions give a true equation under the final form of equation (18), and the coefficient of friction, and the weights of rope, empty cars and loaded cars are fixed, the only method of imparting motion to the system by gravity is by an increase of the angle of inclination of the plane.

Example of Application of the Formula.

Let W, the weight of the loaded car, = 4000 lbs.
Let w, the weight of the empty car, = 1000 lbs.
Let C, the coefficient of friction, = 0.02.
Let the length of the incline = 1000 ft.

Substituting these values in formula (13), we have:

$$\frac{(4000 + 1000)\ 0.02}{4000 - 1000} = 0.0333 = \text{tangent of } 1^\circ\ 54'.$$

This grade gives us a tentative basis for determining approximately the strength of rope required: $4000 \times \sin 1^\circ\ 54' = 133$ lbs. The working load of a $\frac{1}{4}$-in. plow-steel hoisting-rope is 0.6 ton; hence it will be ample for the purpose. One thousand feet of this kind of rope weighs 100 lbs. Substituting this value for r in formula (15), we have

$$\frac{(4000 + 1000 + 100)\ 0.02}{4000 - (1000 + 100)} = 0.03517 = \text{(nearly) } \tan 2^\circ\ 1',$$

the minimum angle for a self-acting inclined plane, exclusive of drum-friction. Assuming that $C' = 0.07$ (which would probably be approximately correct for ordinary drums), and substituting the assumed values in equation (17), we have 0.14 $[(0.03519 \times 1100) + (0.99938 \times 1100)\ 0.02] = 8.5$ lb. Assuming this resistance at 10 lb. instead of 8.5 lb., we have finally, by formula (19),

$$\frac{0.02\ (4000 + 1000 + 100) + \dfrac{10}{0.99938}}{4000 - (1000 + 100)} = \tan a.$$

Noting that we have used the cosine of the angle of $2^\circ\ 1'$ instead of the cosine of the final angle of inclination, and noting, further, that dividing 10 by the cosine would not affect it to the

extent of a unit, we may ignore the cosine for small angles, as it does not materially affect the result; and we then have from formula (19)

$$\frac{0.02\,(4000 + 1000 + 100) + 10}{4000 - (1000 + 100)} = 0.0386 = \text{tangent of } 2^\circ\ 13',$$

the minimum angle for a self-acting inclined plane, with the given weight of rope, empty and loaded car, and the given coefficient of car- and drum-friction. It must be remembered that on this grade of 3.86 per cent. the strain of the loaded car on one hand, and that of the empty car, rope and drum-friction on the other, are equal. A 4 per cent. grade, with a short piece of level track at the bottom and a short piece of heavier grade at the top, would probably operate all right. The accuracy of the solution of the question in any case will be dependent on the accuracy with which the coefficients of friction for the cars and drum are determined. The motive power which sets the system in motion is the weight of the loaded car or cars multiplied by the sine of the angle of inclination; the resisting or retarding forces are the wheel-friction of the loaded car or cars, etc. When the motive power exceeds the sum of the resisting forces, the excess will be an accelerating force, and the velocity acquired in a given time can be calculated from the standard formulas for motion. The force which generates the acceleration in this case is the difference between the motive and resistant forces; and the mass accelerated is the sum of these forces. To obtain the acceleration due to the given forces, moving vertically, we have the conventional formula for partially counterbalanced falling bodies,

$$(20) \qquad \frac{fg}{m} = g^1,$$

in which f is the force generating acceleration; m, the mass accelerated; g, acceleration due to gravity, and g^1, the acceleration communicated to the mass in one second when moving vertically. But in this case the forces considered are moving on an inclined plane; consequently we find the proper value for g^1 to be

$$(21) \qquad \frac{fg \sin a}{m}.$$

If it is desired to impart a given velocity to the system, the space or length of the incline passed over before the velocity can be acquired is found from the formula

(22) $S = \frac{v^2}{2g^1}$, and the time from the formula, (23) $t = \frac{v}{g^1}$.

While the initial impulse which creates motion in the system may be given by either an increase of grade at the top of the plane or a decrease at the bottom, or both, the best practice is to have the grade of the plane as nearly uniform as possible, except a piece of light grade at the bottom, which may be of longer or shorter length according to the velocity it is desired to impart to the system in starting. On inclines of light grade, however, it is necessary to resort to both expedients. The frictional resistance encountered in starting from a state of rest being greater than the friction of motion, we assume that the motive power available for starting the system should be, if possible, twice the sum of the theoretical resistance. Assuming a grade of 4 per cent., or 2° 18′, for our incline, and 1 per cent., or 0° 35′, for the light grade at the bottom, the sum of the theoretical resistances in starting will be: $(0.99919 \times 4000)\ 0.02 + (.01018 \times 1100) + (0\text{-}99995 \times 1100)\ 0.02 + 10 = 123$ pounds. Therefore the sine of the starting-angle $\times\ 4000 = 246$; consequently $\frac{246}{4000} = 0.0615$, the sine of 3° 32′, the proper starting-grade. The motive force generating acceleration on this starting-grade is 246 pounds. Substituting the stipulated values in (21), we have for the value of g^1 on the starting-grade* $\frac{246 - 123}{246 + 123} \times 32.16 \times 0.0615 = 0.659$; and, if it is desired to obtain a velocity of 10 ft. per second on the starting-grade, substituting the stipulated values in (22) we have $S = \frac{100}{2 \times 0.659} = 76$ ft., the length of the starting-grade. If the length of the incline is limited to 1000 ft., we have 76 ft. $\times\ 0.0615 = 4.67$ ft., and, giving to the light grade at the bottom the same length

* The actual value of the fraction of g represented by g prime in the formula is not a constant quantity, but a variable and increasing function (affected by the weight of rope paid out on the loaded side and taken up on the empty side) until the load reaches the light grade, where it decreases and becomes negative.

as the starting-grade, $76 \times 0.01018 = 0.77$; and $40 - (4.67 + 0.77) = 34.56$ ft.; and for the uniform part of the incline, $34.56 \div 848 = 0.04075$, the sine of $2° \ 20'$. Theoretically, the velocity will continue to increase after the loaded car passes on the 4.07 per cent. grade; but the increment will be smaller on account of the decrease in the motive force, and also because it varies as the sine of the angle of inclination. However, as there will still be some increase in velocity, it seems safe to assume that the velocity of 10 ft. per second would be maintained to the end of the 4.07 per cent. grade, and that the load would have sufficient momentum to carry it over the light grade at the bottom, and complete the run. Under that supposition, the time occupied in making the trip would be $848 \div 10 + 15 + 15 = 114.8$, or, say, 115 seconds.* When a back-balance is used to lower the loaded and bring back the empty car, the same principles apply. Of course, differential or cone-drums could be used on inclines to equalize the resistance, and make the motive force uniform throughout the trip.

PROBLEM III.

To Determine the Horse-Power Required to Hoist a Trip of Cars on an Engine-Plane, or to Hoist a Load in a Shaft.

Retaining the notation used above, let V be the velocity in feet per minute, and H P the horse-power sought.

By (7), with the introduction of r, the strain on the rope will be $(W + r) \sin a + C (W + r) \cos a$, and multiplying this by the velocity and dividing by 33,000, we have

$$(24) \quad H\,P = \frac{V\ [(W + r) \sin a + C\ (W + r) \cos a]}{33{,}000}.$$

In this equation it is evident that if the coefficient of friction and the velocity remain constant, the horse-power will vary directly with any increase or decrease of the load, and, in like manner, if the load and coefficient of friction remain constant,

* The same time (15 seconds) is allowed to bring the car to a stop on the flat grade at the foot of the incline as was consumed in acquiring the velocity of 10 ft. per second on the starting-grade. The theoretical time occupied in making the run can be found by using the formula: $s = vt + \frac{1}{2} g' t^2$.

the horse-power will vary directly with any increase or decrease of the velocity. On a double-track inclined plane, where the loaded cars are ascending while the empties are descending, the strain due to the descending empty trip ought to be subtracted from the strain due to the loaded trip, if it is desired to determine the exact amount of power required to hoist the loaded trip. Such refinements had better be ignored in practice, and estimate made for the full amount of power required to hoist the load, irrespective of the counterbalance.

In a vertical shaft with a double hoist-way, if we let

W = Weight of loaded car and cage in pounds,
w = Weight of empty car and cage in pounds,
r = Weight of rope in pounds,

we have for the horse-power required to hoist a load, ignoring friction,

$$\text{(25)} \qquad \frac{(W + r - w)\,V}{33{,}000} = \text{H. P.}$$

This is the power required to hoist the load at the given speed with common cylindrical drums, the empty car and cage being considered as the counterbalance. As remarked in the case of the engine-planes, it is better in practice to estimate for the full amount of power required to hoist the load, irrespective of any counterbalance. In that case, the formula would be

$$\text{(26)} \qquad \frac{(W + r)\,V}{33{,}000} = \text{H. P.}$$

Problem IV.

To Determine the Size of Hoisting-Engines.

A hoisting plant should consist of a pair of engines; and each engine should have ample power to hoist the net load.

The easiest method is to find the foot-pounds per minute required to hoist the load, making proper allowance for the friction of the moving load and machinery, and divide by 33,000. The quotient will be the horse-power which the engine must develop. A manufacturer's catalogue will give the size of engine that will develop the required power. Or, find the

net unbalanced load, in pounds, which the engines are required to hoist; to this add a certain per cent. of the total moving load for friction; and multiply the sum by the speed of hoisting in feet per minute. The product will be the power in foot-pounds per minute required to hoist the load, and, divided by 33,000, will give the horse-power. The ratio of the net useful effort an engine can exert to the total power developed in the cylinder is its efficiency; and the foot-pounds per minute required to hoist load (or the horse-power) divided by the efficiency of the engine will give the total foot-pounds per minute (or horse-power, as the case may be) which the engine must develop in order to overcome all forces resisting motion and hoist the load.

To find the size of engine that will develop the required power, we have, using the conventional symbols, the standard formula

$$(27) \qquad 2\,S\,P\,A\,\theta = \text{foot-pounds per minute},$$

in which S is the length of stroke in ft.; P, the pressure in lbs. per sq. in.; A, the area of the steam-piston in sq. in.; and θ, the revolutions of the engine per minute. To utilize this formula for the solution of our problem we must assume a mean effective steam-pressure in the cylinder, a ratio of stroke to diameter of cylinder, and a number of revolutions per minute. It is evident at a glance that the foot-pounds of energy developed by the engine will be in direct proportion to the increase or decrease of any one of the factors S, P, A and θ.

If x be the diameter of cylinder in inches, and r' the ratio of the stroke to the diameter, we have, by substituting these values in

$$(27) \quad 0.7854\,x^2 \times r'x \times P \times 2\,\theta = \text{foot-pounds per minute, or}$$

$$(28) \qquad x = \sqrt[3]{\frac{\text{foot-pounds per minute}}{0.7854 \times r' \times P \times 2\,\theta}}.$$

It should be noted that in (27) S is given in feet and A in inches, therefore r' represents the ratio of the stroke in feet to the diameter in inches; thus, if the absolute ratio of stroke to diameter is 2 : 1 or $\frac{2}{1}$, the value of r' in our formula is 2 : 12

or $\frac{2}{12}$. Let V be the speed of hoisting in feet per minute; e, the efficiency of the engine; g, the ratio of gearing; D, the diameter of the drum in feet; and L the weight in pounds of the total unbalanced load on the engine. Then

(29) $\dfrac{V}{3.1416\,\theta} = \text{D}$, for direct-acting engines; and

(30) $\dfrac{Vg}{3.1416\,\theta} = \text{D}$, for geared engines; and the maximum

drum-diameter for direct-acting engines will be

(31) $\dfrac{\frac{1}{2}\,\text{S} \times \text{P} \times \text{A} \times e}{\text{L}} = \dfrac{\text{D}}{2}$; and if the engine is geared,

(32) $\dfrac{\frac{1}{2}\,\text{S} \times \text{P} \times \text{A} \times e \times g}{\text{L}} = \dfrac{\text{D}}{2}$.

The determination of the proper size of drum is an important matter. It is evident that, if a rope of a certain size is required to hoist a given load, that consideration alone will fix the minimum size of the drum. If an arbitrary number of revolutions per minute for the engine, conforming to ordinary practice, be assumed, with a given pressure, and the diameter and stroke of the cylinder found which will generate a certain horse-power, and the size of the drum found by formula (29), it is quite possible that the size of the drum so determined will be so small that the rope required to hoist the load cannot be coiled upon it without injury to the rope. The size of the drum ought be taken into consideration in connection with the speed of the engine, the minimum diameter of the drum being determined by the size of the rope, and θ can then be determined by (29) as $\dfrac{V}{3.1416\,\text{D}} = \theta$ for direct-acting engines, or by (30) as $\dfrac{V\,g}{3.1416\,\text{D}} = \theta$ for geared engines.

Examples.

1. In a double-compartment shaft, 500 ft. deep, we want a pair of direct-acting engines capable of hoisting a load each minute. The cage weighs 2000 lbs., the car 1000 lbs., and the coal or ore 3000 lbs. The coefficient of friction of the moving

load is 0.1; the efficiency of the engines is 70 per cent.; the ratio of stroke to diameter is 2 : 1; and the mean effective steam pressure is 60 pounds per square inch. What is the size of direct-acting engines required?

Allowing 30 seconds for caging, the time occupied in each winding will be 30 seconds, and the velocity of the moving load will be 500 ft. ÷ 30 seconds = 1000 ft. per minute. The load the rope must sustain is 2000 + 1000 + 3000 + weight of rope. Assuming a $1\frac{1}{8}$ in. plow-steel rope weighing 2 lbs. per ft., we have 1000 lbs. for weight of rope and 7000 lbs. for the total weight on the rope. Doubling this total load, to provide against jerks (the breaking-strain of the rope being 53 tons), gives us a factor of safety of $53 \div 7 = 7.57$, which is ample. The total moving load is $2000 + 1000 + 3000 + 1000 + 2000 + 1000 = 10{,}000$ lbs.; the friction due to the moving load will be $10{,}000 \times 0.1 = 1000$ lbs.; and the unbalanced load on the engines will be $(2000 + 1000 + 3000 + 1000 + 1000) - (2000 + 1000) = 5000$ lbs.

Five thousand pounds hoisted 1000 ft. per minute gives 5,000,000 ft.-lbs. per minute. The effective horse-power required for each engine is therefore $\frac{5{,}000{,}000}{33{,}000} = 151.5$ horse-power. Each cylinder must develop $5{,}000{,}000 \div 0.70 = 7{,}142{,}857$ ft.-lbs. per minute. The minimum diameter of drum we can use with a $1\frac{1}{8}$-in. rope is 6 ft., its circumference is 18.85 ft. The speed of the hoist is 1000 ft.; consequently $\frac{1000}{18.85} = 53.1$ revolutions per minute. Substituting the stipulated values in formula (28), we have

$$x = \sqrt[3]{\frac{7.142{,}857}{0.7854 \times \frac{1}{6} \times 60 \times 2 \times 53}} = 20.4 \text{ in., or, say, 20 in. diameter and 40 in. stroke.}$$

2. With a 10-ft. drum (which would give the maximum duration for the rope) and all other factors remaining the same, the revolutions per minute would be reduced to 32, and the diameter of cylinder required would be 24.2 in., or, say, 24 in., with a stroke of 48 in.

3. If the load on the engine be assumed at 8000 lbs., while all other conditions remain as in Example 1, the cylinder required would have 23.9, or, say, 24 in. diameter, and 48 in. stroke.

4. For a geared engine running at 150 revolutions per minute and 50 lbs. pressure, all other factors being the same as in Example 1, the ratio of gearing required will be, from (30), $g = \frac{3.1416\ D\ \theta}{V} = 2.827$; and the diameter of cylinder, from (28), $x = \sqrt[3]{\frac{11,428,571}{.7854 \times \frac{1}{6} \times 2 \times 150 \times 50}} = 18$ in. That is, the engines should have 18 in. cylinder-diameter and 36 in. stroke.

Problem V.

Conical Drums.

To Determine the Proper Ratio of Drum-Diameter for a Double Hoist, to Equalize the Load on the Engines so as to Make it Uniform Throughout a Trip.

Let R be the radius of the major diameter, and R^1 that of the minor diameter, in ft.; r, the weight of the rope; W, that of cage, coal, car and rope; w, that of cage and car, and C, that of coal or ore, all in lbs.; and let the depth of the shaft be 502.6 ft. If the drums are properly proportioned, the statical moment which the engines must overcome at any point in the trip (ignoring friction) will always be equal to the average radius $\times$ net unbalanced load, or weight of coal or ore. When the loaded cage is at the bottom of the shaft, its statical moment is WR^1. The empty car and cage being at the top, its moment is wR; and the difference between these will be the statical moment which the engines must overcome. This gives us:

$$(33) \qquad WR^1 - wR = C\left(\frac{R + R^1}{2}\right).$$

For the same reasons, when the load is at the top and the empty car and cage are at the bottom of the shaft, we have

$$(34) \qquad (W - r)R - (w + r)R^1 = C\left(\frac{R + R^1}{2}\right).$$

Equating the left-hand members of (33) and (34), we have

$$(35) \qquad WR^1 - wR = (W - r)R - (w + r)R^1.$$

Transposing and dividing, we have

(36) $$\frac{R^1}{R} = \frac{W + w - r}{W + w + r}.$$

All the symbols of the right-hand member of this equation express quantities known in any given case. Substituting the proper numerical values, the resulting fraction will give the ratio between the radii or diameters of the drums.

Let 2000 lbs. be the weight of the cage; 1000 that of the car; 3000 that of the coal or ore; and 1000 that of the rope. Then

$$\frac{R^1}{R} = \frac{7000 + 3000 - 1000}{7000 + 3000 + 1000} = \frac{9}{11}.$$

Assuming a definite value for either radius, say either 4.5 or 9 ft. for R^1, we have $R = 5.5$ and 11 ft., respectively. With drums of this form, the effort which the engines are required to exert will be equal and uniform throughout the trip, as the difference between the moments of the loaded and empty cage at any point on the trip will always be equal to $C\left(\frac{R + R^1}{2}\right)$.

Assuming the same stipulations as in the second example given above for cylindrical drums (the mean drum-diameter being 10 ft.), the unbalanced load in this case being the coal or ore only, we have as the ft.-lbs. per minute required to hoist a trip — (net load + friction) $\times v = (3000 + 1000) \times 1000 =$ 4,000,000 ft.-lbs. per minute, and the nominal foot-pounds each engine must develop will be $4,000,000 \div 0.70 = 5,714,857$; and according to (28), $x = \sqrt[3]{\frac{5,714,857}{.7854 \times \frac{1}{6} \times 60 \times 2 \times 32}} = 22.5$ in. of cylinder-diameter, or, say, engines of 22 by 44 in. cylinders.

With cone-drums having a mean diameter of 6 ft. and all other conditions as stipulated in the first example, we have from (28) $x = \sqrt[3]{\frac{5,714,857}{0.7854 \times \frac{1}{6} \times 60 \times 2 \times 53}} = 19$ in. for cylinder-diameter, and stroke of 38 in. It is evident that the weight of the rope is the measure of the advantage obtained by the use of the cone-drums; consequently the advantage will be slight in shallow shafts, and will increase as the depth of the shaft increases.

Commencing at the small end of the drum, each succeeding

lap of the rope is longer than the preceding one by a common difference, thus forming an increasing arithmetical progression. To find the common difference, the length of any lap, or the sum of any number of laps, we have the conventional formulas:

(37) $$d = \frac{l - a}{n - 1}$$

(38) $$l = a + (n - 1)\, d$$

(39) $$s = (a + l)\frac{n}{2},$$

in which d is the common difference; n, the number of laps; a, the length of the first lap of the series; l, the length of the last lap of the series; and s, the length of the sum of the laps of the series.

In the case under discussion, assuming a drum of 11 ft. major and 9 ft. minor diameter, we have

$$d = \frac{34.5576 - 28.2744}{16 - 1} = 0.419 \text{ ft.}$$

The sum of the series, or 16 laps with the given diameter, must be 502.6 ft., or the total depth of the shaft. The cages will be opposite each other on the completion of the eighth revolution of the drums. To find the sum of the first eight laps we must find the length of the eighth lap. Substituting numerical values in (38), we have:

$$l = 28.2744 + (8 - 1) \times 0.419 = 31.2074 \text{ ft.},$$

as the length of the eighth lap. Substituting numerical values in (39), we have

$$s = (28.2744 + 31.2074)\tfrac{8}{2} = 237.9 \text{ ft.},$$

the sum of first eight laps. Hence, when eight revolutions have been made, the ascending cage will be 237.9 ft. from the bottom of the shaft, and the descending cage will be opposite it, or 264.7 ft. from the top, as that is the sum of the eight laps on the greater diameter of the drum. The ascending cage will thus be 13.4 ft. from the half-way point of the shaft at the completion of the eighth revolution, and the descending

cage 13.4 ft. past it. But 13.4 ft. is 0.42 of the ninth lap; so that the drum will have made 8.42 revolutions when the ascending cage passes the half-way point in a shaft 502.6 ft. deep, and the descending cage will be down from the top 8.42 laps on the large end of the drum, or $264.7 + 13.1 = 277.8$ ft., that is, 26.5 ft. past the half-way point in the shaft. In like manner, it may be shown that the descending cage will pass the half-way point in the shaft when the drum has made $8 - 0.42 = 7.58$ revolutions, and that the ascending cage will then be 26.5 ft below the half-way point.

Some Principles Controlling the Deposition of Ores.

BY C. R. VAN HISE, MADISON, WIS.

[Concluding Contribution of Prof. Van Hise to the Discussion of his Paper, and Others on the Same General Subject, presented at the Washington Meeting, February, 1900 (see *Trans.*, xxx., 27, 177, 323, 424, 578); also of the contributions of Vogt, De Launay, Beck, Lindgren, Kemp, Rickard, Bain, Keyes, Collins and Adams, presented at the Richmond Meeting, February, 1901, and to be printed in the present volume.]

In June, 1900, shortly after my paper was published in the *Transactions*, I made a briefer statement* before the Western Society of Engineers covering the same ground, which, in certain respects, is somewhat of an improvement. For instance, instead of using the terms *descending* and *ascending* with reference to the waters resulting in the two concentrations, my modified statement is as follows:

"The first concentration of many ore-deposits is the work of a relatively deep water-circulation, while the reconcentration is the result of reactions upon an earlier concentration through the agency of a relatively shallow water-circulation. Commonly the deep water-circulation is lacking in free oxygen, and contains reducing agents, and the shallow water contains free oxygen. The deep water is therefore a reducing, and the shallow water an oxidizing agent."†

Of the papers upon ore-deposits which, in vol. xxx. of the *Transactions*, follow my own, or which were presented at the Richmond meeting, a considerable number are wholly con-

* *Jour. of Geol.*, vol. viii., 1900, pp. 730–770.

† *Ibid.*, p. 765.

firmatory of the conclusions which I have presented. Among these are the Washington paper of Emmons upon the Secondary Enrichment of Ore-Deposits* and his discussion at Richmond of other papers,† that of Weed upon the Enrichment of Gold and Silver Veins,‡ the discussion of Emmons', and at Richmond of Weed's paper by Collins† and Prof. De Launay,† the paper of Lindgren on Metasomatic Processes in Fissure Veins,§ that of Rickard upon the Formation of Bonanzas in the Upper Portions of Gold Veins,|| and the remarks of Bain upon the Mississippi Valley lead- and zinc-deposits.¶ It is therefore unnecessary to discuss these papers; but in this connection those of Messrs. Emmons and Weed are of interest, since their main purpose is to emphasize and illustrate one of the principles stated by me, which they have independently worked out and used; namely, the principle of secondary concentration by descending waters, not only in the belt above the level of ground-water, but in the sulphide belt below that level. This principle, as well as many of the others stated in my paper, I have been presenting to my students for a number of years. Messrs. Emmons and Weed working at Washington, and I at Madison, were wholly unaware that similar work was being done elsewhere, and that identical conclusions had been reached. If independent investigation by different men leading to the same results be evidence of the truth of a conclusion, the principle of secondary enrichment by descending waters has such confirmation.

A second class of papers, and especially the admirable papers of Vogt upon the Geology of Ore-Deposits,** of Lindgren upon the Character and Genesis of Certain Contact Deposits,†† and a part of the discussion by Prof. Beck,† have apparently been interpreted by some as presenting views radically different from mine. Two fundamental points which Lindgren, Vogt and Beck emphasize are that the main source of the metallic ores is the igneous rocks, and that the heat of the igneous rocks has been instrumental in their production. With these positions I not only agree, but definitely advocate the same ideas in my paper, as is shown by the following quotations:

---

* *Trans.*, xxx., 177. † See under "Discussions" at the end of this volume.
‡ *Trans.*, xxx., 424. § *Ibid.*, 578. || This volume, p. 198.
¶ See under "Discussions" at the end of this volume.
** This volume, p. 125. †† This volume, p. 226.

"The original source of much of the material for the metalliferous deposits may, indeed, be largely the centrosphere or the lower part of the lithosphere; for from these sources vast masses of volcanic rocks are injected into the zone of fracture or brought to the surface. This is especially true during great periods of vulcanism. Furthermore, it is well known that in regions of volcanic rocks many ore-deposits are found. Also it is believed that all the rocks of the lithosphere were originally igneous, and that from these igneous rocks the sedimentary rocks have been derived by the epigene forces, *i.e.*, the forces working through the agencies of atmosphere and hydrosphere. It follows, therefore, that the metals of ore-deposits, either directly or indirectly, are derived from igneous rocks. However, the ores are directly derived from rocks in the zone of fracture by circulating underground waters. The rocks which furnish the metallic compounds may be intruded igneous rocks; they may be extruded igneous rocks; they may be the original rocks of the earth's crust; they may be sedimentary rocks derived by any of the processes of erosion from primary rocks; they may be the altered equivalents of any of these classes."*

* * * * * * *

"The nature of the rocks which contribute the metallic salts has been much discussed. With Sandberger, I have little doubt that the metallic constituents of ores are in large part derived from the igneous rocks which have been intruded or extruded into the lithosphere; and especially is this true of the basic rocks. Le Conte points out that the undoubted frequent occurrence of workable ore-deposits in regions of vulcanism may be explained by the heat furnished by the igneous rocks, this promoting the work of underground solutions. That the heat furnished by the igneous rocks is a very important factor in the production of ore-deposits, I have no doubt. Since it is very difficult to prove that the metallic content of an igneous rock is original, it is impossible to make any general statement as to whether the metallic content or the heat furnished by the igneous rocks is the more important in the production of ore-deposits. It seems to me clear that both are important; and equally clear, in many cases, that both work together. That is to say, an igneous rock may furnish all or a part of the metal which appears in an ore-deposit, and the heat of the same igneous rock may greatly assist its concentration by the underground waters.

"While the massive igneous rocks are the undoubted source of a large portion of metallic deposits, it is also equally certain that another large part is derived from the sedimentary rocks and the metamorphosed, or partly metamorphosed, igneous and sedimentary rocks. Lastly, it is also certain that many ore-deposits derive their metalliferous content in part from igneous rocks and in part from sedimentary rocks. Probably this is the most frequent of all cases. To give any estimate of the relative amounts of metalliferous materials derived from the original igneous rocks and from the secondary rocks is quite impossible."†

Prof. Vogt holds that ore-deposits may be formed by magmatic segregation, but that such "differentiation"-ores are "confessedly infrequent."‡ With this conclusion I concur in every particular, and in my classification made a place for ores of this kind: "(A) Ores of Igneous Origin."§ Although agreeing that this class exists, I do not concur in the conclusion that all of the ores specifically mentioned by Vogt as be-

* "Some Principles," etc., *Trans.*, xxx., 45–46.

† *Ibid.*, 91–92.

‡ This volume, p. 131.

§ *Trans.*, xxx., 29, 30, 173.

longing to it are produced by magmatic segregation alone, without modification by the underground water-circulation. Prof. Vogt holds, however, that the ore-deposits formed by so-called eruptive after-actions are much more important than those directly produced by magmatic segregation. In this class of deposits he places cassiterite-veins, apatite-veins, and pegmatite-veins. Only the first of these groups yields a metallic product; and to the metallic ores my paper is confined. There is nothing in it which can be interpreted as disagreeing with these conclusions of Prof. Vogt, since I refer to no tin-deposits whatever as the product of underground water, and have maintained, as will be seen just below, that the pegmatite veins are connected with igneous action.

But the main contention of Prof. Vogt, and one of the principal ones of Dr. Lindgren, is that there is a large class of ore-deposits of contact-metamorphic origin. The existence of this class I have also distinctly recognized. I say:

> "In another place I have explained that there are gradations between different classes of rocks, and this statement applies equally well to ore-deposits. I even hold that there are gradations between ore-deposits which may be explained wholly by igneous agencies, and those which may be explained wholly by the work of underground water, or by processes of sedimentation."*

Also, in my article in the *Journal of Geology* I say:

> "I have elsewhere held that there is complete gradation between waters containing rock in solution and rock containing water in solution. If there be no sharp separation between water solutions and magma, it is probable that this is also true in reference to ore-deposits of direct igneous origin and those produced by underground water."†

The fact that I clearly recognize this class of deposits is fully appreciated by Dr. Lindgren, who quotes one of the statements above given, and also the following from my paper upon North American pre-Cambrian Geology:

> "It is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. If this be so, then there will be all stages of gradation between true igneous injection and aqueous cementation, and all the various phases of pegmatization may thus be fully explained."‡

---

* *Trans.*, xxx., 174. † *Jour. of Geol.*, vol. viii., 1900, p. 768.

‡ "Principles of North American Pre-Cambrian Geology," by C. R. Van Hise. 16*th Ann. Rept. U. S. Geol. Surv.*, Part I., p. 687 (1895).

It therefore appears that, so far as the classes of ore-deposits are concerned, there is no difference of opinion between myself and Prof. Vogt and Dr. Lindgren. We all agree that the class of contact-deposits exists; that the source of the ores of such deposits is largely the igneous rocks; and that during the concentration of the ores a high temperature prevailed. The difference of opinion occurs in the interpretation of particular cases. Prof. Vogt and Dr. Lindgren, but more especially the former, hold that many ore-deposits, including sulphides, are more closely allied to the igneous rocks than to water-deposits; while I hold that the majority of ores, and especially those included under "Other Contact-Deposits" by Vogt,* as shown by their character and relations, are deposited by underground waters. However, I have distinctly recognized that there may be deposits in which it is difficult to say which of these two agencies predominate. For instance, in the *Journal of Geology* I say:

"There may be ore-deposits in which water-action and magmatic differentiation have been so closely associated that one cannot say whether the resultant ore-deposit is mainly a water-deposit or mainly a magmatic deposit."†

But in the vast majority of cases I hold that there is little difficulty in discriminating between veins and dikes—the first representing crystallizations from water-solutions; the second, crystallization from magma. There are few cases where the discrimination with reference to ore-deposits is not easy. While gradations between water-deposited ores and igneous ores are uncommon, gradations between the different classes of ore-deposits formed by underground water are common.

Concerning pneumatolytic action as an auxiliary in the formation of ores, as held by Vogt, Lindgren, Beck and Kemp, I do not deny the existence of ores of this class, but simply say that, while ore-deposits produced by this process are theoretically possible, and very likely exist, I do not know of any instance in which it has been shown that pneumatolytic action has actually been a dominating factor in the production of a workable ore-deposit. However, I think it not unlikely that pneumatolytic action (in the sense of water-gas under very high

* This volume, pp. 139, 140, 147.
† *Jour. of Geol.*, vol. viii., 1900, p. 768.

pressure, above the critical temperature of water) may have helped in the segregation of the metals by transporting them to the main channels of water-circulation. This condition of the water I distinctly recognize* as producible not only by igneous rocks, but also by dynamic action. But discrimination should be made between what may be true and what has been shown to be true. The presence of such so-called contact-minerals as tourmaline and fluorite, holding such elements as boron and fluorine, is not proof that they and the other minerals in the veins containing them were not deposited by heated circulating waters.

From the proposition that igneous rocks are an important source of the ores, and that the ores are extracted from them by circulating waters, it by no means necessarily follows that this work is chiefly done while the rock is a fused liquid mass. After the rocks crystallize and become partly cooled, deformation, and the cooling itself, may produce many fractures in them, thus furnishing channels through which the hot waters course while they are collecting the metals. In this manner is largely explained the difficulty under which Prof. Kemp labors in understanding how circulating waters may work upon hot igneous rocks.† So far as igneous rocks are deep-seated intrusives, they may retain after crystallization a very large part of the water which they previously held. This is evidenced by the innumerable liquid inclusions in many such rocks.

In this connection I may say that, among the papers presented in this discussion, Lindgren's admirable paper upon metasomatic processes in fissure-veins seems to me wholly to confirm the view that the deposition of most metallic deposits is effected by underground water. The metasomatic changes in the rocks which Dr. Lindgren describes occur not only in the veins themselves, but in the walls of the veins. Moreover, in many cases the amount of change decreases in passing from the walls into the veins. During the metasomatic changes, metals were added and subtracted. Lindgren declares that, in the great majority of these cases, the chief agents through which the metasomatic changes were accomplished were circulating waters. He says:

---

* *Trans.*, xxx., 38.

† This volume, pp. 176, 177, etc.

"The processes observed are such as can only be explained by aqueous agencies. Possible exceptions are the forms of alteration connected with cassiterite, apatite, and tourmaline veins, in which pneumatolytic conditions may have partly obtained."*

He concludes, further,† that the waters were probably hot; that those which originally deposited the sulphide constituents were probably ascending; but that the ascending waters are chiefly of surface-origin. Therefore, in all these matters, by his exhaustive study of the metasomatic processes in the veins, Dr. Lindgren fully confirms my most fundamental contentions.

It is noteworthy that Prof. Vogt and Dr. Lindgren, with admirable scientific restraint, notwithstanding the beliefs which they hold, discriminate clearly between the few cases in which they have shown a probability that the ores are the products of igneous action and the far more numerous cases in which the evidence of such origin is very scanty or wanting altogether. Says Prof. Vogt:

"That the ore-deposits first mentioned above, viz., the titanic iron-ores in gabbro, the chromite-occurrences in peridotites, the nickel-pyrrhotite deposits in gabbro, etc., were formed by magmatic extraction, I think I have scientifically proved beyond doubt; and I believe that the magmatic-extraction theory advanced for the cassiterite- and apatite-veins is in its main proposition correct. For the ore-deposits subsequently considered,—the contact-deposits, the pyritic deposits, the gold-veins, silver-lead veins, copper-ore veins, etc.,—the views here offered become confessedly more and more hypothetical. But they have much in their favor; and even if, following in particular the French observers, I have here ascribed to magmatic-extraction too great a significance, I believe, nevertheless, that the hypothesis is worthy of thorough scientific discussion."‡

Thus Prof. Vogt recognizes clearly that the attribution of the larger class of these ores to igneous action is purely hypothetical. He fully appreciates that, of the great majority of ore-deposits, he has wholly failed to show that igneous agencies have separated the ores from the original rocks and placed them in their present positions. This connection must be made before the hypothesis advanced by Prof. Vogt can hope for acceptance. Since the majority of the ore-deposits thought by Prof. Vogt to be possibly due to "contact after-action" in some other sense than segregation by underground water differ in no essential particulars as to their character, the minerals they

* *Trans.*, xxx., 690. † *Ibid.*, 691. ‡ This volume, p. 147.

contain, the relations of these minerals to one another, the relations of the ores and minerals to the surrounding rocks, the presence of crustification, and other features, from ore-deposits which many authorities, including Prof. Vogt, recognize as deposited by underground water, I shall hold to the old view that they are the results of water-deposition until evidence is presented showing the contrary. To attempt to prove the proposition that these ores are deposited by water would require the repetition throughout of the arguments for such an origin which have been presented during the past half-century by nearly all of the famous men who have discussed ore-deposits. If these arguments are not adequate to convince the reader, I cannot, in closing this discussion, present the case more fully, but must defer the matter until the publication of my treatise upon Metamorphism, in which I consider much more fully the circulation and work of underground water, and the character of the deposits produced by that agent.

If it be recognized that, in the majority of the cases cited by Vogt and Lindgren, the materials of the ores were transported and deposited in their present positions by underground waters, it makes no difference to me whether such ore-deposits be called contact-deposits, hydro-thermal deposits, dynamo-metamorphic deposits, or regional metamorphic deposits, as proposed by Lindgren.*

As I have pointed out,† dynamic action may increase the temperature of the underground waters, and make the conditions much more favorable for the deposition of ores. If in the first part of my paper, discussing general principles, I have not made clear my belief in the extreme efficiency of hot water, as compared with that of cold water, in the segregation of ores, I have failed altogether to convey my ideas. I fully recognize the remarkable relative potency of hot water in all classes of alterations of rocks, including the deposition of ores. I emphasize especially the effect of high temperature, (1) in producing a deeper circulation,‡ (2) in producing a more rapid circulation,§ and (3) in very greatly increasing the power of water to do chemical work of all kinds. For instance, I say:

* This volume, pp. 240, 241.

† *Trans.*, xxx., 49.

‡ *Ibid.*, 43.

§ *Ibid.*, 48–51.

"But pure water at a high temperature is a potent solvent. Barus has shown that water at temperatures above 185° C. attacks the silicates composing soft glass with astonishing rapidity. At 180° C. various zeolites can be dissolved in pure water, the material crystallizing out on cooling. Lemberg shows that water at 210° C. slowly dissolved anhydrous powdered silicates. It is therefore apparent that water in the lower part of the zone of fracture is a most potent chemical agent."*

With this conclusion the following quotation shows that Prof. Vogt agrees:

"As is well known, the ionization of water increases rapidly with its temperature. This explains the activity of water at high temperatures. Thus, for example, Barus has shown that water heated above 185° C. attacks the silicates composing soft glass with astonishing rapidity; and an experiment by Lemberg has proved that water at 210° C. slowly dissolves anhydrous powdered silicates."†

Further, I strongly make the point that both the speed of solution and the amount of material which may be taken into solution are greatly increased by high temperature;‡ and in proof of the efficacy of hot water in the production of ore-deposits, I cite the Cordilleran region of the West§ as one in which the temperature of the water is higher than normal, and in which ore-deposits are common.

In conclusion as to this portion of the discussion, I would say that, while I think I have given adequate weight to igneous rocks as a source of the ores, and to the resultant hot waters as an agency in their concentration, I have not elaborated that branch of the subject. The reason is, that these ideas are not new, but have been generally accepted for decades by all who have written upon ore-deposits. A complete treatise upon ore-deposits should, of course, give proportional representation to all parts of the subject; but a paper on the subject necessarily covers the new ground most fully; and if, in addition to this, it puts new material in its proper relations and proportions to old material, that is all that can be fairly expected.

I have reserved for separate consideration most of the points raised in Prof. Kemp's paper upon "The Rôle of the Igneous Rocks in the Formation of Veins,"|| with the arguments and conclusions of which I am not in such general agreement as

---

* *Trans.*, xxx., 53. † This volume, p. 132. ‡ *Trans.*, xxx., 65, 66.
§ *Ibid.*, 49, 50. || This volume, pp. 169–198.

with those of the other papers named. I shall state the points both of agreement and of difference between us; and, I need hardly say, with entire personal esteem and respect for Prof. Kemp. But my position is rendered somewhat embarrassing by the circumstance that this contribution closes the discussion, so far as it is to be published by the Institute in the special volume now in press.

1. From the frequent occurrence of ore-bodies in regions of vulcanism, it does not follow, as held by Prof. Kemp,* that the igneous rocks are the sole source, or, in some cases, even an important source of the ores. As pointed out by Prof. Le Conte many years ago, and as shown by me in my paper (*Trans.*, xxx., 91, 92), "the undoubted occurrence of workable ore-deposits in regions of vulcanism may be explained by the heat furnished by the igneous rocks, this promoting the work of the underground solutions." I have already emphasized the enormously increased activity of solutions with rise of temperature. In the neighborhood of igneous rocks the underground solutions are hot, and these hot solutions may, and in many cases, I believe, undoubtedly do, derive a large part of their metallic material from the sedimentary or metamorphosed rocks, although, as indicated in my original paper,† I maintain that probably the ultimate source of all the ores, and very frequently the chief or sole immediate source, has been the igneous rocks.

2. While Prof. Kemp would derive the majority of ores from igneous rocks, he declares‡ that surface-flows of such rocks are unfavorable to vein-formation. But, to give an instance to the contrary, the Lake Superior copper-deposits were shown by Pumpelly, years ago, to occur in or associated with surface volcanic rocks. I think the true statement is, that in most districts very recent volcanic flows have not had time enough for the development of contained or connected ore-deposits; or else, they have not been eroded deeply enough to expose such deposits, if they exist. But in the San Juan region of Colorado, where denudation has taken place on a vast scale in very late geological time, great ore-deposits do occur in Tertiary volcanic rocks; and it would be rash to say that ore-deposits are

* This volume, pp. 175, 197, 198.
† *Trans.*, xxx., 45–46.
‡ This volume, p. 183.

not even now forming in the middle and lower parts of the great lava-flows of the plateaus of the West. Indeed, I think it highly probable that such formations are going on, and that at some future period the resulting ore-deposits will be at the surface.

3. In asserting the existence of gradations between pegmatite and quartz-veins, I am glad to find Prof. Kemp in full accord with me. I pointed out such gradations some years ago, and, as already explained, advanced as the explanation that water and rock, at sufficiently high temperatures and pressures, are miscible in all proportions.

4. From Prof. Kemp's statement* that "practically all students of volcanic phenomena are agreed that steam and its dissociated representatives in the molten rock are the chief, if not the only, cause of eruption," I must wholly dissent, holding with Dutton and Gilbert† that, in areas of regional vulcanism (which are those containing the most extensive ore-deposits), gravitative stress is the dominant force producing eruption, although it is agreed that steam plays a subordinate part, and an important part in local vulcanism.

5. Perhaps I do not fully appreciate Prof. Kemp's arguments‡ concerning capillary attraction as connected with the movements of underground water. Prof. Kemp says that the imperviousness of strata is partly due to the "feebleness or disappearance of capillary attraction with increase of pressure." On later pages he says: "Whenever, for example, capillary transmission occurs, the previously acquired head is lost, and the emerging water proceeds on its way only under a newly accumulating head." Further, he says that "capillary attraction is largely an ascensive force." I am uncertain whether or not Prof. Kemp intends to imply that I have advocated the view that capillarity is an important force which accounts for the circulation of groundwater in the belt of saturation. As a matter of fact, I have

---

* This volume, p. 176.

† "Geology of the High Plateaus of Utah," by C. E. Dutton, *Rept. of U. S. Geogr. and Geol. Surv. of the Rocky Mt. Region*, Washington, 1880, pp. 113–142.

"Geology of the Henry Mts.," by G. K. Gilbert; *Id.*, pp. 66–74.

"Earth-Movements," by C. R. Van Hise. *Trans. Wis. Acad. Sci. Arts and Letters*, vol. xi., 1898, pp. 495–502.

‡ This volume, pp. 187, 190, 193, 197.

not appealed to the force of capillarity in any way whatever to explain the circulation in this belt. It seems to me that Prof. Kemp has wholly failed to recognize the great difference in the nature and forces which control the circulation of water in the belt of weathering, above the level of groundwater, and the belt of cementation, below that level.* Above the level of groundwater the force of capillarity is important in the movement of groundwater. This matter I shall discuss fully in my treatise on Metamorphism, but cannot take up here, as it is a complicated one. Below the level of groundwater, the size of the openings, as I have fully explained,† is of very great importance in the movement of the underground water, because friction runs up very rapidly with subdivision of the openings; but how capillarity is a "descensive" or "ascensive" force in this belt, I am at a loss to understand.

6. Prof. Kemp does me an unintentional injustice when he cites me as supporting "the view that hot springs are the result of normal terrestrial circulations, without accessions of heat other than those which would be received through the ordinary increase of temperature with depth."‡ I refer the increase of temperature of the underground waters to the normal increase of temperature with depth, to *vulcanism, and to dynamic action.*§ Regional vulcanism and orogenic movements I mention twice as producing high temperature.

7. But I held, and still hold, that difference in temperature of the ascending and descending columns is a cause which works in the promotion of circulation as an adjunct to the main cause, head. Prof. Kemp‖ argues against this conclusion in the following way:

"(3) That water under great load or pressure does not expand according to the 4 per cent. rate named (*i.e.*, 4 per cent. for 100° C.). On the contrary, it may be held by the pressure at fixed volume, despite the added heat. If, for example, we roughly assume a column of water 1 sq. in. in cross-section and 2 ft. high (it is really about 2 ft. 3½ in.) as equal to a pressure of a pound to the square inch, in 10,000 ft. we would have a pressure of something near 5000 lbs., or over 2 tons to the square inch; and in the face of this, the expansion of water from an added temperature of 100° C. practically becomes a negligible quantity as contributing to hydrostatic head."

---

* See my remarks, *Trans.*, xxx., 72.

† *Ibid.*, 40–45.

‡ This volume, p. 192.

§ *Trans.*, xxx., 49.

‖ This volume, p. 193.

This argument seems to me to be unsound for the following reasons:

a. Since I emphasize vulcanism and orogenic movements as chief causes of high temperature in underground water, the depth, and therefore the pressure, may be but a small fraction of that assumed by Prof. Kemp.

b. The only experiments which I have found upon the compressibility of water at high temperature are those of Barus,* in which he finds that the compression resulting from the pressure cited by Kemp is much less than would be necessary to neutralize the expansion due to the heat mentioned.

c. Admitting for the moment that the pressure does neutralize the expansion due to heat, since the pressure is nearly the same upon both the ascending and descending columns, and inasmuch as, under the hypothesis, there is a difference in temperature between the two columns, there would be a difference in density, and therefore a cause for flowage.

8. Upon another point connected with the circulation of underground water, Prof. Kemp says:

> "(4) We must bear in mind also that the standing body of cold groundwater fills the interstices of all rocks near the surface, except those in very arid regions, and exerts a retarding influence on uprising currents."‡

I am entirely at a loss to understand how the coldness of the water prevents circulation due to difference in head and difference in temperature of the two columns, except as to an effect which I have emphasized,† namely, that due to varying viscosity.

After the arguments above mentioned, Prof. Kemp says:

> "I regard it as extremely improbable that the water of any natural spring whose flow is due simply to hydrostatic head, has ever reached more than a very limited depth below the point of emergence."‡

We have already found that difference in temperature of the descending and ascending columns are excluded by Prof. Kemp as an effective cause of deep circulation. The force to which he appeals to explain the deep circulation is that which proceeds from the igneous rocks. He says:

---

* "The Compressibility of Colloids," by C. Barus; *Am. Journ. of Sci.*, 4th ser., vol. vi., 1898, pp. 287–289.

† *Trans.*, xxx., 43.

‡ This volume, p. 192.

"I will even go so far as to say that it is in the highest degree improbable that any waters which have reached depths even approximating 10,000 ft. can ever again reach the surface and yield flowing springs, except through the propulsion of stores of energy contributed by still heated masses of igneous rock."*

I, of course, maintain that the heat-energy of the igneous rocks passes into and thereby expands the water, thus causing a difference in density between the ascending and descending columns,† and thereby promoting circulation. But Prof. Kemp has just thrown this use of the energy of the igneous rocks out of consideration; and how this energy acts in producing a circulation, unless it be by heating and thereby expanding the water, he does not explain.

9. Prof. Kemp says that "standing water in abandoned shafts is strong evidence of the impenetrability of rocks."‡ This seems to me untenable. Such standing water has come in either from the surface, or through the "impenetrable rocks." The latter hypothesis Prof. Kemp rejects. But if the former be true, why does not the water rise with periodic additions? According to my view, standing water in shafts, exactly as in wells, indicates the upper limit of the belt of saturation. But the standing water maintains its uniform level (in the absence of pumping) by flowage through the rocks, compensating the local additions or subtractions. Certainly the water standing in the wells of the drift-covered regions of North America does not prove that there is no active underground circulation in the drift.

Passing from specific points concerning the circulation of underground water, I, of course, largely dissent from Prof. Kemp's general view upon this subject, and can only refer to the argument already given in my paper.§ If the evidence there presented, showing that the main source of the underground water depositing the ores is meteoric, and not derived from the igneous rocks, as held by Prof. Kemp (but without giving adequate evidence), does not prove the point, it is useless further to discuss the matter here. In my treatise on Metamorphism I shall cover this part of the subject much more exhaustively. While I hold that the main source of the water

* This volume, p. 193.

† *Trans.*, xxx., 47–49.

‡ This volume, p. 197.

§ *Trans.*, xxx., 29–79.

depositing ores is meteoric, I recognize that another source of such water is the igneous rocks. I say:

"Also, through the agency of vulcanism, water occluded in magma is transferred from the zone of rock flowage, or even possibly from the centrosphere, to the zone of rock-fracture."*

Nor am I able to accept Prof. Kemp's statements as to the small amount and local deficiency of groundwater. He says, "In regions when the rainfall is small," . . . . "if the rocks are shattered, standing groundwater may be entirely lacking."† And again, "The groundwater may entirely fail in arid regions."‡ I know of no region in the United States which justifies these statements.

While I have never advocated a universal uniform underground circulation, as implied by Prof. Kemp, I have held, and still hold, that the amount of underground water and its circulation is much more general than he believes. This problem may be considered, first, from the point of view of the amount of underground water now present; and second, and more important, the amount of work which has been done by underground water.

Upon the first point, it is contended by Prof. Kemp that the amount of underground water in the belt of saturation is usually small; but in opposition to this view we have the general experience of mining men and of those who by wells seek underground water. While there are notable exceptions, it is in general a difficult and expensive process to lower artificially the level of groundwater which is generally found in both humid and arid regions, though at greater depth in the latter. In the lead- and zinc-districts of Missouri, this operation, called by the miners "beating the water," is usually attempted only by a number of companies, acting jointly, and constitutes the most formidable part of mining-work.

In Wisconsin, it is a grave hindrance to mining below water-level. The lowering of the groundwater by, say, 50 ft., is an exceedingly difficult task, involving enormous expenses for pumping. The subsequent holding of the water at a given level is much easier, as Prof. Kemp has noted. But my conclusions from these facts are that, in the belt of saturation, the openings are large and the quantity of water is great, but the

* *Trans.*, xxx., 47. † This volume, p. 195. ‡ This volume, p. 197.

circulation is, in most cases, not too rapid to be controlled by pumps of moderate capacity—although, in some cases, to hold the water at a given level involves the handling of vast quantities of underground water.

In this connection Prof. Kemp remarks* that the circulation at smaller depths than 1500 or 2000 ft. has no bearing on the question of ore-deposition. While a few ore-deposits have been profitably worked to a greater depth than this, it is well known that probably more than 90 per cent. of the metallic wealth of the earth yet mined has come from above the 2000-ft. level; and therefore there is no warrant for the statement that the circulation above this level is not of vital importance in the production of ore-deposits.

In this matter of depth, Prof. Kemp asserts,† of the general circulation of underground water, that "something like 2000 ft. appears to be its limit;" but the only evidence which he presents upon this point is that in some cases this is the fact. The local instances cited are not, to my mind, proof of such a law. On the other hand, the evidence which I have presented to the contrary is reinforced by the arguments of Prof. Vogt,‡ which, combining the facts of observed depth of denudation of veins with the likeness of their deeper parts to those parts nearer the surface plainly produced by underground waters, clearly lead to the conclusion that, in many cases, the underground circulation must have been efficient to a depth several times greater than 2000 ft.

On the second point, the work of underground water, Prof. Kemp declares that veins are the exceptional, not the general, work of this agency. He says that while veins occur locally in mining districts, there is a "general absence of veins."§ If Prof. Kemp means *mineral* veins, this is of course true; but if he means literally what he says (and it is only with this meaning that any argument can be made as to the circulation of underground water), I wholly dissent from the conclusion. In my field-work throughout the United States and considerable areas of Canada I have yet to find a district in which a series of rocks has been in the belt of saturation for a long time geologically in which there are not extensive, metasomatic changes in the

* This volume, p. 188.

† This volume, p. 187.

‡ This volume, p. 158 *et seq.*

§ This volume, p. 196.

rocks, and many veins. For instance, in the Appalachian region, almost innumerable veins, the work of underground water, may be seen from Maine to Alabama; but only very rarely and locally are there important ore-deposits. Therefore the localization of mineral (*i. e.*, ore-bearing) veins gives no information as to the general circulation of underground water.

While I repeat that I have never advocated a universal, uniform, vigorous underground circulation, as implied by Prof. Kemp, I have held and still hold that, almost universally, in those places where ore-deposits occur, a vigorous circulation was going on during the time the ores were deposited; and at the only places of which I know where ore-deposits are now forming, such a circulation is going on. The fact that some areas in which ore-deposits are now worked do not now show a vigorous circulation has no bearing upon the question of the deposition of these ores by underground water. The very process of vigorous circulation by underground water results in the cementation of the openings, as I have fully explained.* In so far as the innumerable openings are filled, and during the process here and there ore-deposits are formed, just to that extent the openings are closed. When the openings have been filled to such an extent that they become subcapillary, circulation practically ceases for the time. But subsequent earth-movements or igneous intrusions may again produce openings in the rocks, and thus a new circulation may be set up. Of course it is well known that in the deep copper-deposits of the Lake Superior region, and at various other localities, as at Przibram, there is not now a vigorous underground circulation. I cannot believe that Prof. Kemp therefore dissents from the conclusion of Pumpelly, Irving, and others, that in the Lake Superior region the deposits of copper in the openings of the conglomerates and amygdaloids, extending to a depth of 5000 ft. or more, are the cementation-result of circulating underground waters. Posepny realized full well that when the ore-deposits were formed at Przibram, there was a vigorous circulation of underground waters at a depth below 1100 meters. With regard to the formation of the deep deposits of Lake Superior, Przibram, and many other localities in all parts of the world, cited by Posepny, in some of which there is now but a feeble circula-

* *Trans.*, xxx., 72–79.

tion, I am but a follower of Sandberger and Posepny and nearly all the eminent geologists who have written upon ore-deposits, in the belief that these ores were put in place by underground waters. In whatever respects I may differ from Sandberger or Posepny, there is absolute identity in our fundamental contention that the great majority of the metallic ores, to the greatest depth penetrated by man, were deposited in the places where they now exist by circulating underground waters. Probably Prof. Kemp does not intend to argue, although his reasoning could be so interpreted, that because there is not at present a vigorous circulation where ore-deposits exist, such ores were not deposited by the circulation of underground water.

While it is clear that the underground circulation is much more vigorous and widespread than is believed by Prof. Kemp, and while I first discuss the circulation which would take place in a homogeneous medium,* I follow with what I regard as one of the most essential points of my paper, viz., the elaborate evidence presented of the very unequal and variable character of the underground water-circulation, due to unequal temperature caused by normal increase, vulcanism and dynamic action; the preferential use by water of large channels;† the variation of the rocks in porosity and structure; the complexity and irregular distribution of the openings; the intersections of fractures; the successions of fractures; the impervious strata at various depths; the pitching troughs and arches; etc.‡ Prof. Kemp speaks§ also of the importance of impervious strata in influencing the circulation of groundwater. I have strongly emphasized|| the very profound influence of impervious strata upon the deposition of ores, and have explained that the difference between pervious and impervious strata is that pervious strata have openings of capillary or supercapillary size, while the openings of impervious strata are subcapillary.

The localization of ore-deposits, of which Prof. Kemp speaks,¶ I have shown to be due to the fact that each case of the formation of a deposit "requires the fortunate combination of many favorable factors working harmoniously together, the absence of any one of which may prevent the concentration of

* *Trans.*, xxx., 51–60. † *Ibid.*, 60–62. ‡ *Ibid.*, 138–172.
§ This volume, p. 187. || *Trans.*, xxx., 141–161. ¶ This volume, p. 196.

the ore-deposit."* Only here and there have existed the remarkable combination of circumstances necessary to form an ore-deposit, and thus once in a million times, or once in ten million times, a vein formed carries a sufficient amount of the valuable metals to be an ore.†

Therefore, notwithstanding the contrary belief of Prof. Kemp, I again assert that the deposition of the great majority of ore-deposits—namely, those produced by underground water—is a special case of the general work of underground water, which can only be adequately explained by a profound knowledge of the facts and principles controlling the circulation and work of underground water, and a detailed knowledge of the special modifications necessary to explain the localization and relations of the ores.

In closing this discussion I must express deep gratification for the kindly and appreciative manner in which my attempt to solve some of the problems of ore-deposition has been received by the men who have discussed it. Indeed, the papers of Lindgren, Vogt, Beck and Rickard speak of the paper in a more complimentary way than I could have hoped. When I published it, I anticipated that it would be regarded as too theoretical by geologists who are at work in the field upon the fascinating problem of ore-deposition, and especially by the practical men who are in charge of the development of large mining properties. In this respect, however, I have been wholly mistaken; for the most hearty appreciation which has come to me has been from these two classes of men.

In conclusion, I can only say that I find in the various papers following my own so much which confirms my conclusions (and no reason which appears to me to be sound, advanced against any of them) that, after a careful consideration of all that has been said, I find it unnecessary to modify my paper (beyond the changes in the *Journal of Geology* to which I have referred) either as to statements of facts and conclusions, or as to their proportional importance.

---

* *Trans.*, xxx., 166.

† See my article, *Jour. of Geol.*, vol. viii., 1900, p. 753.

A Study of the Effect of Heat-Treatment on Crucible Steel Containing One Per Cent. of Carbon.

BY GEORGE W. SARGENT, READING, PA.

(Richmond Meeting, February, 1901.)

FOR the experiments here described a rod was used, 0.75 in. in diameter, and rolled from one ingot. Analyses of the ingot and rod showed them to have the following composition respectively:

	C. Per cent.	Mn. Per cent.	Si. Per cent.	P. Per cent.	S. Per cent.
Ingot, . . .	1.150	0.328	0.223	0.020	0.016
Rod, . . .	1.033	0.327	0.223	0.020	0.016

Pieces 4 in. long were heated to various temperatures in a closed porcelain tube, within a gas furnace, and allowed to cool with the same; they were then turned, threaded, and subjected to physical tests in a Riehlé testing-machine. The elastic limit was determined by the drop of the beam. The elongation was measured in two inches. From the threaded ends of the test-pieces, disks were cut, and prepared by combined polishing and etching, using parchment stretched over a wooden block and moistened with a 2-per cent. solution of ammonium nitrate. The structure, as thus developed, and the fractures, were magnified and photographed.

A cooling-curve was constructed, and the critical point was located at 675°–680° C. A thermo-electric pyrometer was used to make the measurements of temperature.

The micro-constituents of steel have been so frequently and thoroughly described by others that I need only say here that the theoretical micro-structural constituents of this steel were: pearlite, 95; ferrite, 0; cementite, 5 per cent.

The quenched metal would be expected to consist almost entirely of martensite—provided, however, the quenching be done at or near the proper temperature. Rapid quenching from a high temperature would give rise to austenite.

Effect of Heat-Treatment on Fracture.

Figs. 1 to 10, inclusive, show fractures after heating to successively higher temperatures, under the conditions stated. From Fig. 1 to Fig. 3 the fracture is seen to become closer, and from Fig. 3 to Fig. 9 coarser, in grain. In Figs. 7, 8 and 9, the grains are apparently isometric (octahedral) crystals. Fig. 10 also shows these crystals, in size between those of Figs. 8 and 9. These are the fractures of the pieces broken in the testing-machine. Where crystallization had occurred, the breaks followed the crystal-faces. In no instance could I perceive that a crystal had been torn apart. The crystals occur singly or in groups in a magma of amorphous metal.

Effect of Heat-Treatment on Micro-Structure.

Figs. 11 to 34, inclusive, exhibit this effect. Fig. 11 (untreated steel) shows on close examination a crystalline structure, represented on a larger scale in Figs. 21 and 22. The crystals are composed of lamellar pearlite, joined together by cementite. In size, shape and appearance they are identical in the longitudinal and transverse sections of the piece; but Figs. 21 and 22 do not show this fact clearly. No attempt was made to measure the size of the crystals; success, in this case, being deemed doubtful.

As the temperature approaches the critical point, 680° C., the crystals disappear, and a homogeneous mass of pearlite results which is not lamellar, but granular. As the temperature increases the pearlite becomes again lamellar, and is formed into crystals surrounded by cementite, growing larger as the heat is increased until, at 915° C., all the cementite has left the boundaries of the individual pearlite crystals and gone towards binding groups of the pearlite crystals into larger compound crystals. The individual crystals are only to be distinguished by the difference in direction of their lamellæ. At 1025° C., these compound or secondary crystals, much increased in size, are taking on more of a geometrical form, which is very pronounced at 1150° C. Fig. 28 shows the juncture of four crystals of pearlite united by cementite. In Figs. 29, 30 and 31, the effect of heating to high temperatures, cooling slowly, reheating to the critical point, and holding there for a greater or less time, is shown. The cementite is represented by dark lines or apparent

fissures in Figs. 18, 19, 27 and 31. This is due in part to focussing, and in part to the preparation of the section.

Figs. 32, 33 and 34 show the effects of quenching at different temperatures. The critical point of this steel is 675°–680° C., and yet, when quenched at 680° C., the microstructure is that shown by Fig. 32. The steel can still be filed, although it has been very appreciably hardened. When this result was first obtained, it was thought to be an error; but repetition confirmed it. Pearlite seems to be present, and cementite, attempting to form it into crystals or grains. Martensite is also present. Fig. 33 is composed entirely of martensite; this piece was quenched at 750° C., or 70° above the critical point. The structure exhibited by the steel quenched from 1100° C. is quite coarse martensite (or austenite) in crystals with cementite. When plunged, this piece cracked—the cracks following the cementite.

Effect of Heat-Treatment on Physical Properties.

For convenience, the results of the physical tests are given here in tabulated form:

Temperature. Deg. C.	Elastic Limit. Lbs. Per Sq. In.	Tensile Strength. Lbs. Per Sq. In.	Elongation in 2 In. Per cent.	Reduction of Area. Per cent.	Figures.
Untreated	83,550	149,200	7.0	10.5	1, 11, 21, 22
650	75,650	134,850	9.0	17.5	2, 12, 23
680	63,150	104,950	22.0	44.0	3, 13, 24
700	63,200	105,600	19.5	34.0	4, 14, 25
737	68,250	122,700	7.0	14.5	5, 15, 26
823	70,650	120,000	4.0	4.5	6, 16, 27
915	64,850	127,000	7.0	8.5	7, 17
1025	60,700	128,850	4.5	4.5	8, 18
1150	64,800	79,800	0.4	0.5	9, 19
900 (2.5 hrs.)	61,900	122,200	3.5	3.0	10, 20, 28
1000 and afterwards to 680.	55,150	103,600	22.0	42.0	29
1150 and afterwards to 680.	60,850	110,350	14.0	33.5	30
900 (2.5 hrs.) then to 680.	62,000	108,400	15.0	37.0	31
Quenched at 680.	80,450	176,200	12.0	8.1	32

As the temperature increases from 680° C., the critical point, there is a decided loss in elongation and reduction of area. A variation of but 20° C. changes the reduction of area from 44 to 34 per cent., and the elongation from 22 to 19.5 per cent.

Mr. Morse,* from a carbon-steel containing 0.34 per cent. C, obtained the best results after annealing at 900° C., while an increase of 190° above that temperature only reduced the reduction of area from 54 to 44 per cent., and the elongation but slightly. Yet when the steel was heated to any temperature below 900° C., the lowest reduction of area was 48 per cent., with elongation little changed.

A comparison of the results obtained from the piece heated to 1025° C. and immediately allowed to cool, with those obtained from the piece heated to 900° C. for $2\frac{1}{2}$ hrs., indicate that prolonged heating gives the results obtained by quick heating to a higher temperature. This was less distinctly marked in the case of lower-carbon steel, viz.: the 0.34 per cent. carbon-steel of Morse.

Fig. 35 shows graphically the tests of Mr. Morse as well as those shown in the preceding table.

Turning to the physical tests of the pieces heated to a high heat and reheated to 680° and taking the first instance, where the steel was first heated to 1000° C., it is seen that the excessive heat has not greatly injured the steel. The reheating restored it almost to its original condition. The piece heated to 1150° C., cooled, and reheated to 680° C., shows the effects of the high temperature to which it was subjected; but the reheating has almost restored it. In both these instances the steel was maintained at 680° C. not more than 2.5 minutes. This was sufficient to destroy the effects of the overheating in the first instance, but not in the second. The steel heated at 900° C. for $2\frac{1}{2}$ hrs., cooled and reheated to 680,° and immediately allowed to cool, was somewhat benefited by the reheating; but the length of time during which the steel was at 680° C. was not great enough to permit of the complete eradication of the effects of holding it at 900° C. for 2.5 hrs.

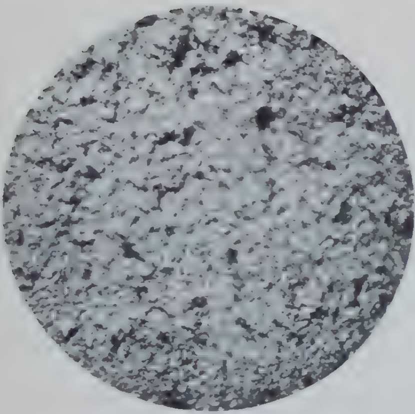
So far as elastic limit and tensile strength are concerned, the quality of the untreated specimens does not seem to have been equalled by the treated bars. This is probably due to the more rapid cooling of the untreated bar.

Summary.

The steel best able to withstand sudden strains, shocks, etc., is the one possessing the highest elongation and reduction of

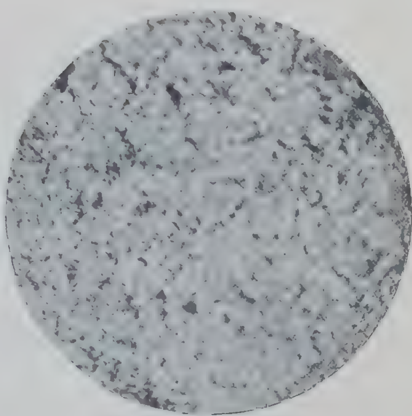
* *Trans.*, xxix., 729.

FIG. 1.



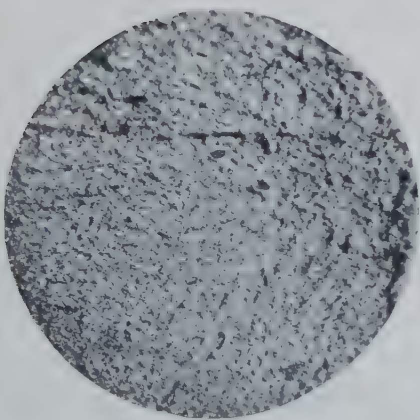
Fracture of Original Steel. (18.75 Diameters.)

FIG. 2.



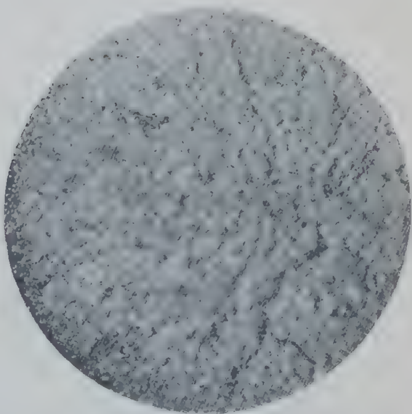
Fracture after Heating 40 min. to 650° C., and Cooling 40 min. to 300° C. (18.75 Diameters.)

FIG. 3.



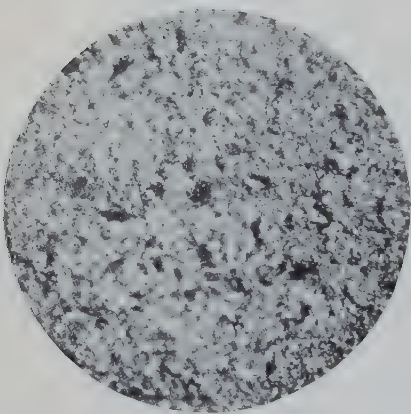
Fracture after Heating 36 min. to 680° C., and Cooling 44 min. to 300° C. (18.75 Diameters.)

FIG. 4.



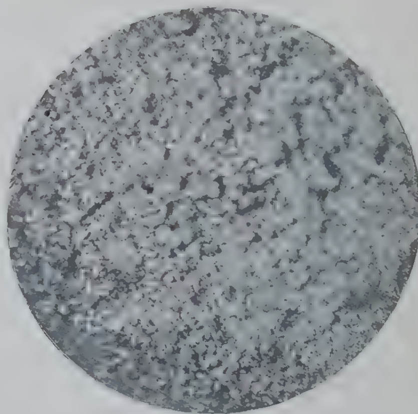
Fracture after Heating 40 min. to 700° C., and Cooling 50 min. to 300° C. (18.75 Diameters.)

FIG. 5.



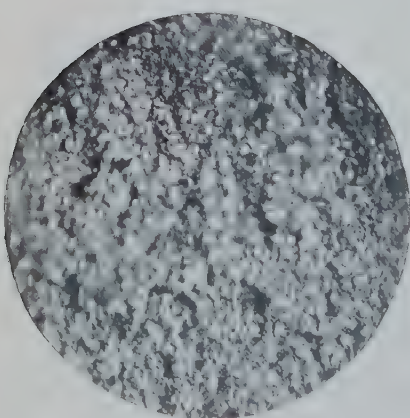
Fracture after Heating 40 min. to 737° C., and Cooling 50 min. to 300° C. (18.75 Diameters.)

FIG. 6.



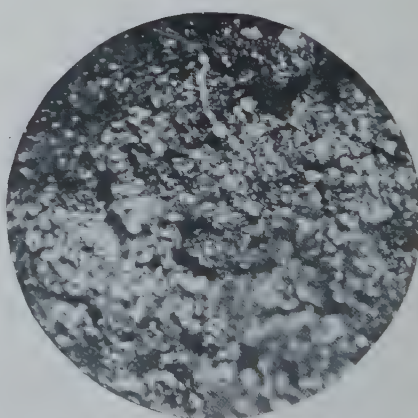
Fracture after Heating 70 min. to 823° C., and Cooling 60 min. to 300° C. (18.75 Diameters.)

FIG. 7.



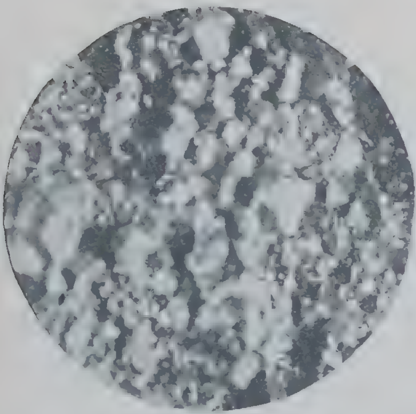
Fracture after Heating 50 min. to 915° C., and Cooling 50 min. to 300° C. (18.75 Diameters.)

FIG. 8.



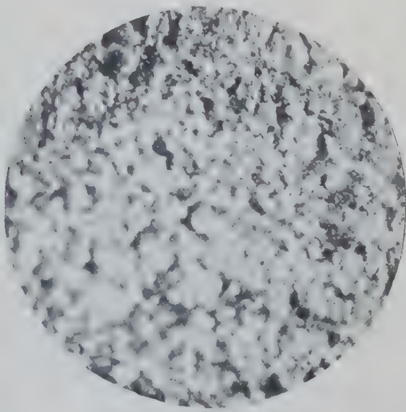
Fracture after Heating 45 min. to 1025° C., and Cooling 60 min. to 300° C. (18.75 Diameters.)

Fig. 9.



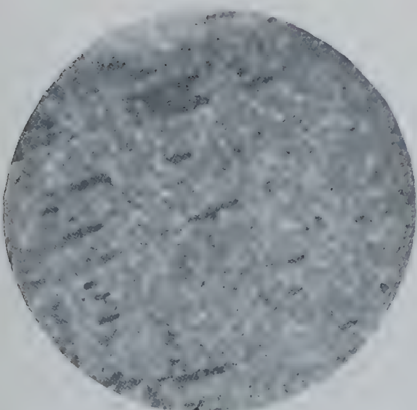
Fracture after Heating 2 hrs. to 1150° C., and Cooling 70 min. to 300° C. (18.75 Diameters.)

Fig. 10.



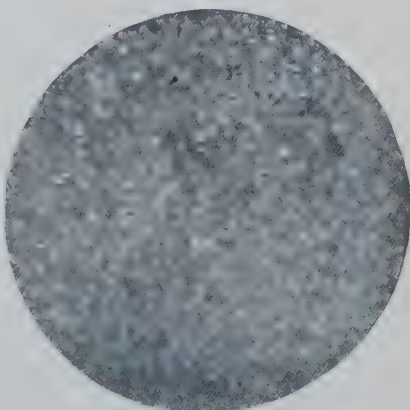
Fracture after Heating to 900° C., and Holding at that Temperature $2\frac{1}{2}$ hrs. (18.75 Diameters.)

Fig. 11.



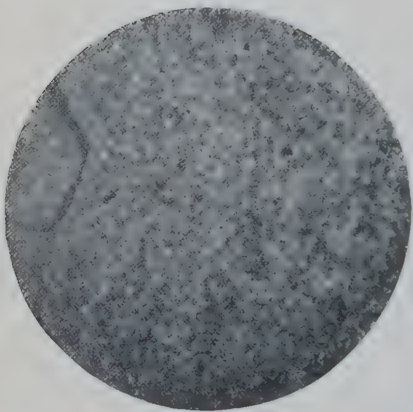
Microstructure of Original Steel. The spots are due to rust on the section (50 Diameters.)

Fig. 12.



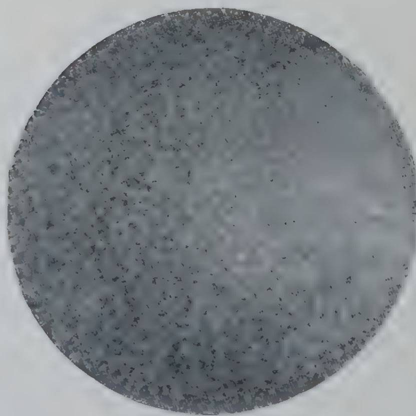
Microstructure Corresponding to Fig. 2. (50 Diameters.)

FIG. 13.



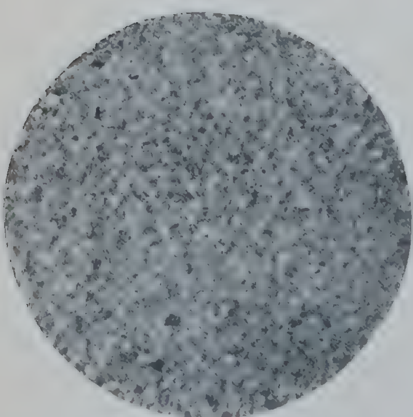
Microstructure Corresponding to Fig. 3.
(50 Diameters.)

FIG. 14.



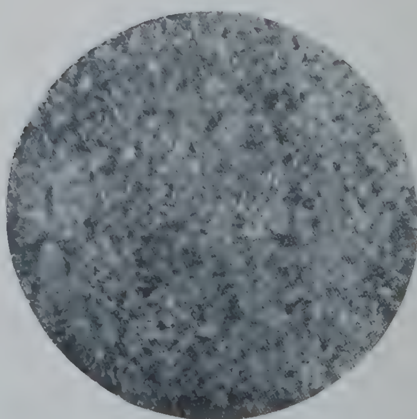
Microstructure Corresponding to Fig. 4.
(50 Diameters.)

FIG. 15.



Microstructure Corresponding to Fig. 5.
(50 Diameters.)

FIG. 16.



Microstructure Corresponding to Fig. 6.
(50 Diameters.)

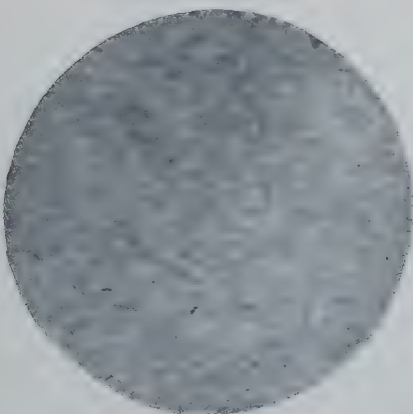
FIG. 17.

Microstructure Corresponding to Fig. 7.
(50 Diameters.)

FIG. 18.

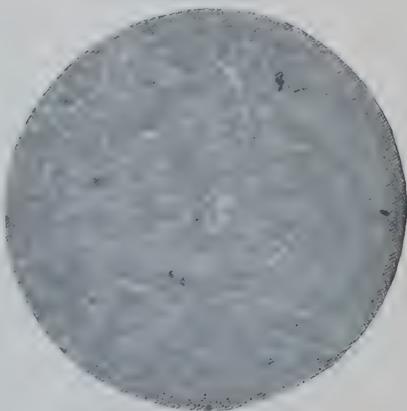
Microstructure Corresponding to Fig. 8.
(50 Diameters.)

FIG. 19.



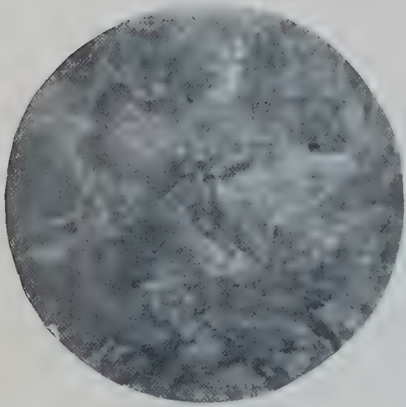
Microstructure Corresponding to Fig. 9.
(50 Diameters.)

Fig. 20.



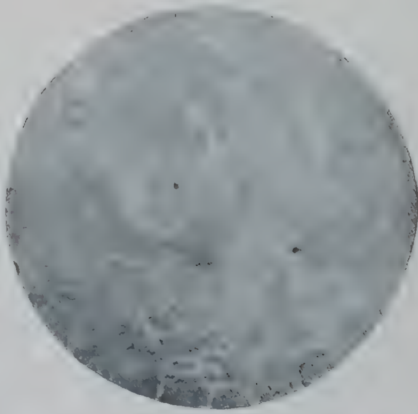
Microstructure Corresponding to Fig. 10.
(50 Diameters.)

FIG. 21.



Microstructure of Original Steel, Longitudinal Section. (335 Diameters.)

FIG. 22.

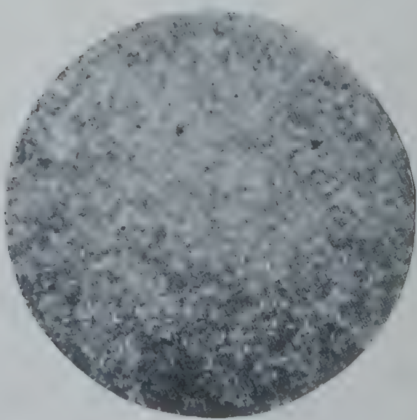


Microstructure of Original Steel, Cross-Section. (335 Diameters.)

FIG. 23.

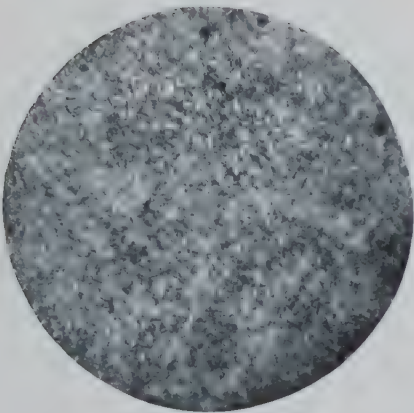
Microstructure Corresponding to Figs. 2 and 12. (335 Diameters.)

FIG. 24.



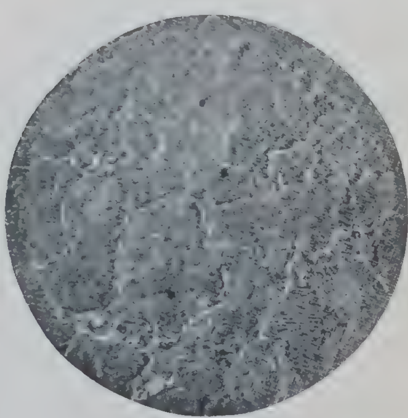
Microstructure Corresponding to Figs. 3 and 13. (335 Diameters.)

Fig. 25.



Microstructure Corresponding to Figs. 4 and 14. (335 Diameters.)

Fig. 26.

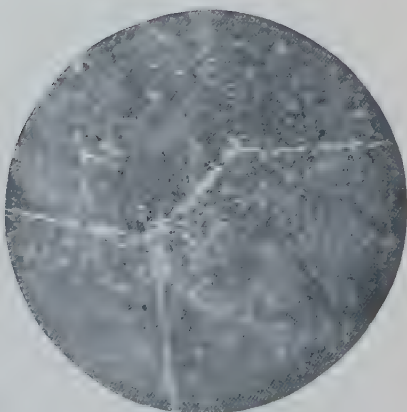


Microstructure Corresponding to Figs. 5 and 15. (335 Diameters.)

Fig. 27.

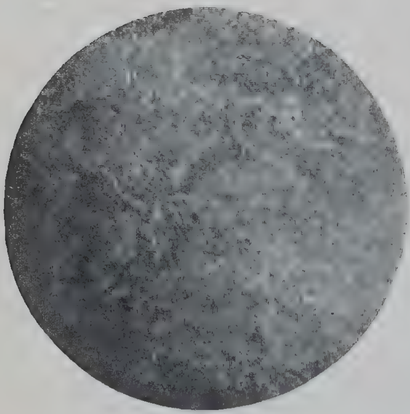
Microstructure Corresponding to Figs. 6 and 16. (335 Diameters.)

Fig. 28.



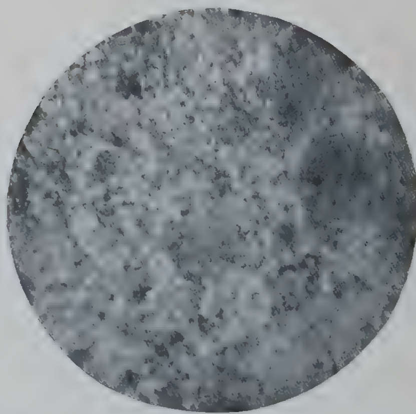
Microstructure Corresponding to Figs. 10 and 20. (335 Diameters.)

FIG. 29.



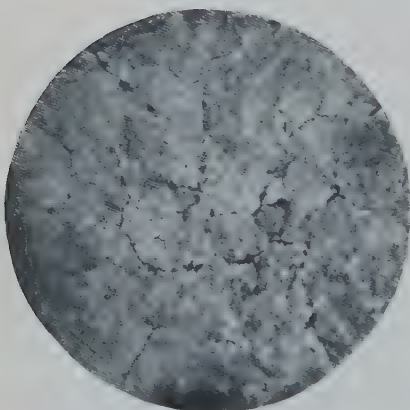
Microstructure of Steel Heated to 1000° C., Cooled Slowly, Reheated to 680° C., and Held at that Temperature a few Minutes before being Allowed to Cool. (335 Diameters.)

FIG. 30.



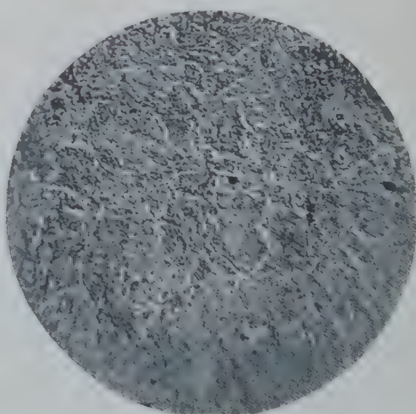
Microstructure of Steel Heated to 1150° C., Cooled Slowly, Reheated to 680° C., and Held at that Temperature a few Minutes before being Allowed to Cool. (335 Diameters.)

FIG. 31.



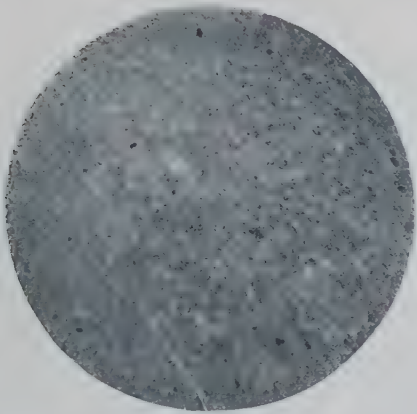
Microstructure of Steel Heated 2½ hrs. to 900° C., Cooled Slowly, Reheated to 680° C., and at once Allowed to Cool. (335 Diameters.)

FIG. 32.



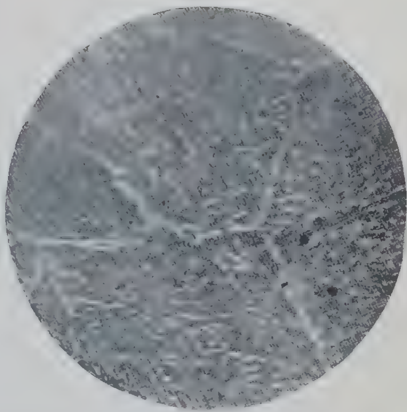
Microstructure of Steel Quenched in Water from 680° C. (335 Diameters.)

FIG. 33.



Microstructure of Steel Quenched in Water from 750° C. (335 Diameters.)

FIG. 34.



Microstructure of Steel Quenched in Water from 1100° C. (335 Diameters.)

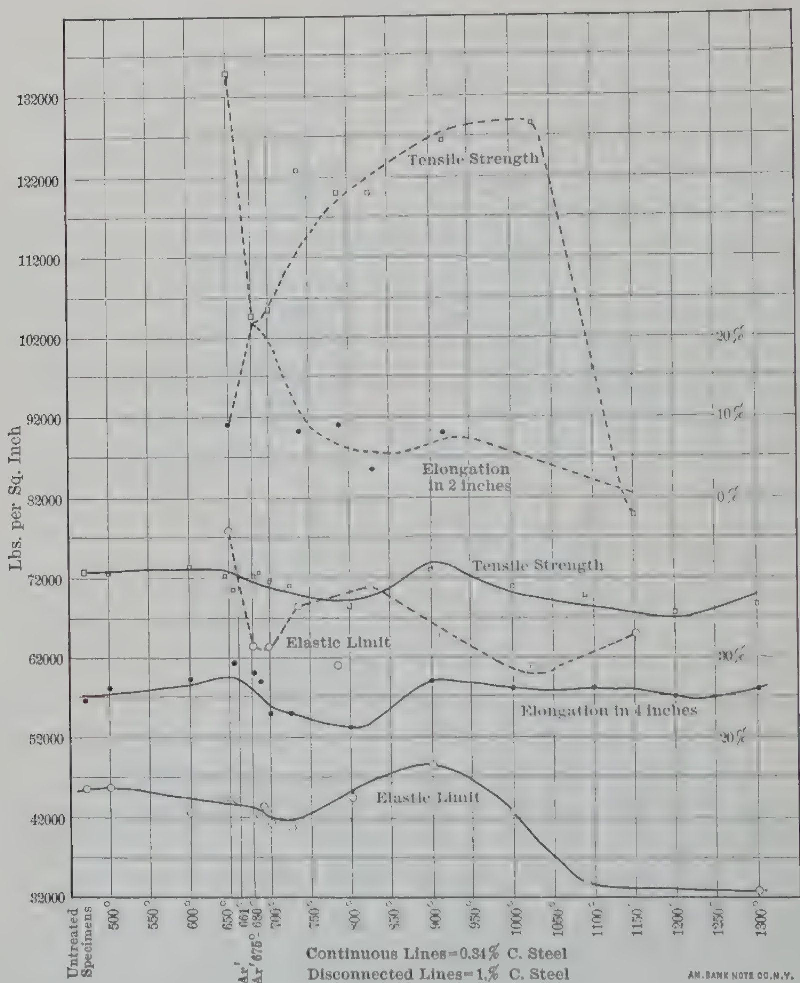
area with a fair elastic limit and tensile strength. The toughest steel, then, would be that finished or annealed at or near the critical temperature. This statement, I believe, applies to all carbon-steels composed of pearlite and cementite. It does not seem to be true of the 0.34-per cent. carbon-steel upon which Morse worked; but if the figures given by him* as representing the elongation are plotted, the resulting curve shows a rise in the neighborhood of Ar_1, as does that obtained with the 1-per cent. carbon-steel; and the 0.34-per cent. carbon-steel finished or annealed near the critical point (661°) would almost equal that finished at 900° C.

Temperature. Deg. C.	Elastic Limit. Lbs. per sq. in.	Tensile Strength. Lbs. per sq. in.	Elongation. Per cent. in 4 in.	Reduction of Area. Per cent.
654	44,030	71,610	29.0	52.0
680	42,440	72,060	28.0	50.0
900	46,460	73,430	27.0	54.0

In the high-carbon steel finished or annealed at the critical point, the cementite is evenly distributed throughout the pearlite, which is granular. This variety does not seem to have the strength of the lamellar, but the latter exists only in crystals,

* *Trans.*, xxix., 745.

FIG. 35.



Effect of Heat-Treatment on the Physical Properties of Steel Containing 0.35 and 1 per cent. of Carbon Respectively.

surrounded by cementite, which latter becomes the thicker, the larger the crystals of pearlite; and, since cementite is brittle, it detracts from the toughness of the mass.

That cementite is brittle is evidenced by the manner in which the elongation and reduction of area fall as the pearlite crystals become larger and the cementite binding them is thicker.

Examination of the piece heated to 1150° C. shows that the

fracture has taken place over the faces of the crystals; that is, it has followed the material binding the crystals, which is seen in Fig. 19 to be cementite. This piece had practically no elongation or reduction of area. The elastic limit of the piece was passed but a few pounds, when the break took place.

A comparison of the curves of the 0.34-per cent. C. steel and the 1-per cent. C. steel shows that the effects of changes in temperature are more marked in high-carbon than in low-carbon steel, and that slight changes in temperature produce, both in structure and physical properties, more decided effects in the case of the former.

Steel finished (as the untreated specimen evidently was) above the critical point shows no difference in the size of the grains or crystal, between longitudinal and transverse sections.

Large crystals of pearlite, like large crystals of ferrite, are made up of smaller crystals. To show this, the etching must be very light.

Heating to a given temperature for a long time produces results similar to heating to a higher temperature for a short time.

The injury done by high heating can be overcome in a large measure by subsequent heating to the proper temperature and holding there for a greater or less time, depending upon the degree to which the steel was overheated.

Studies similar to the foregoing have been conducted with low-carbon steels; but little has been published about such work done on high-carbon steel, such as is used for tools. This is largely owing, no doubt, to the fact that structural and rail-steels enter into the industrial field to a larger extent. The need, however, for a thorough study of tool-steels is none the less urgent.

The value of micro-structural investigation in connection with tool-steels is exceedingly great, although it is not considered so by most manufacturers. Much steel returned to the mill as worthless is in reality good; but, owing to the customer's lack of information as to the proper method of handling the material, it has been spoiled. If such is the case, the microscope will reveal it. Again, manufacturers would gain by issuing more explicit instructions with their goods. These instruc-

tions should be based on a thorough study of the steel, and given in such language as the man who handles the steel will readily understand. The use of a good, cheap form of pyrometer would aid both customer and manufacturer.

This study has been made possible through the generosity of Mr. W. B. Kunhardt, of the Carpenter Steel Co., of which the writer is chemist, and in the laboratory of which the work has been done. I trust it may prove of some value and interest.

The Constitution of Cast-Iron, with Remarks on Current Opinions Concerning It.

BY H. M. HOWE, COLUMBIA UNIVERSITY, NEW YORK CITY.

(Richmond Meeting, February, 1901.)

I. General Statement.

It has seemed to the writer that one important, and indeed sufficient reason, for our slow progress in learning the relation between the chemical composition and the physical properties of cast-iron, has been that the problem has not been attacked properly. It would be well to select the most probable working hypothesis which we can find, and proceed to test that hypothesis by comparison with observed facts, and by making new observations specially designed for such a test. Our first step, then, is to select the most probable working hypothesis; and to attempt this selection, to state the hypothesis and its immediate corollaries, and to take some first steps toward testing it, is the object of the present paper. Its chief purpose is to bring the hypothesis to the attention of those who are more familiar with the evidence than the writer can pretend to be, and in a better position both to present new evidence and to discuss it.

The hypothesis here selected is, that composition governs properties in the case of cast-iron, in the same general way and for the same reasons as in the case of steel, *mutatis mutandis*. This hypothesis, which of course makes no claim to originality, certainly seems reasonable and probable; its exposition and discussion are made easy by our existing knowledge of the constitution of normal or "carbon" steel; it therefore seems worthy of consideration.

Carbon-steel, when cooled slowly, consists essentially of two components:*

(1) *Ferrite*, pure iron, weak, soft, ductile, copper-like.

(2) *Cementite*, a definite carbide of iron, Fe_3C, containing 6.67 per cent. of carbon, harder than glass or hardened steel, extremely brittle, and probably strong like glass under gradually-applied axial stress; its carbon is the "combined carbon," the "carbide carbon" of Ledebur.

The way in which ferrite and cementite habitually interstratify to form the composite mass, pearlite, will be considered in Section III.

When the carbon-content reaches a certain high limit, the exact position of which we need not here try to settle (taking it, however, provisionally, as somewhere between 2 and 3 per cent.), the metal ceases to be called steel, even if it be nearly or quite graphite-less, and it is henceforth called white cast-iron. But we may here regard both steel and white cast-iron as really one unbroken series, varying progressively from the softest tube-steel with 0.06 per cent. of carbon through the die- and file-steels to white cast-iron. The name, white cast-iron, applied to the most highly carburetted part of the series really indicates no break in that series, which is simply like a London street, with different names in different parts, for the convenience of the Londoner and the exasperation of the traveler.

Turning now to common or graphitic cast-iron and regarding it as composed of two distinct and unlike parts, (1) graphite and (2) its metallic part or matrix, which includes everything except the graphite, our natural working-hypothesis is to assume

---

* For the purposes of a mere bird's-eye view of the subject I have purposely left out of consideration many points which a complete exposition would demand. For instance, I speak of steel as graphite-less, whereas in fact steels rich in carbon often carry an appreciable amount of graphite; yet being relatively graphite-less, it is better for our present purpose to speak of them as containing no graphite. So, too, I speak of the combined carbon of cast-iron as existing in the form of cementite; whereas in point of fact many analyses of cast-irons which appear to have been cooled with at least moderate slowness report, along with the cementite, considerable quantities of combined carbon in the condition of martensite, or "hardening-carbon." But for our present purpose we may disregard this, especially as its effect in a general way is similar to that of cementite, making the metal hard and brittle.

In like manner, I leave out of view in this sketch the effects of silicon, manganese, etc., and of thermal and mechanical treatment.

that the properties of any individual cast-iron as a whole depend (1) on the percentage of graphite which it contains, and (2) on the properties of the matrix; and further to assume that this matrix is, both in its constitution and in its properties, substantially like steel, or white cast-iron, of the same carbon-content. Let me here insist on this view that the graphitic cast-irons are by constitution a binary conglomerate, composed of a foreign body, graphite, and of a metallic part or matrix: and that this matrix is in each case simply some one member of the steel-white-cast-iron series, being soft steel, hard steel, or white cast-iron according to whether its combined-carbon content is low, intermediate, or high. This conception is the essence of our hypothesis.

For example, in this view, those graphitiferous cast-irons which contain less than 2 per cent. of combined carbon are essentially steel of like carbon-content, plus graphite; while such cast-irons with more than say 3 per cent. of combined carbon are simply white cast-irons of like combined-carbon-content, plus graphite. Cast-iron with 0.25 per cent. of combined carbon and 3.75 per cent. of graphite is steel of 0.25 per cent. carbon, say structural steel, weakened and embrittled by 3.75 per cent. of graphite; cast-iron with 0.50 per cent. of combined carbon and 3.5 per cent. graphite is steel of 0.50 per cent. carbon, say rail-steel, weakened and embrittled by 3.5 per cent. of graphite; cast-iron with 1.25 or 1.50 per cent. of combined carbon is steel of 1.25 or 1.50 per cent. of carbon, say file-steel, weakened and embrittled by graphite. Cast-iron with 3 per cent. of combined carbon plus 1 per cent. of graphite is essentially a mechanical mixture of (1) 99 parts of white cast-iron containing 3 per cent. of combined carbon, and (2) 1 part of graphite.

To recapitulate, we have:

1. The graphite-less or steel-white-cast-iron series, consisting essentially of ferrite and cementite.

2. The graphitic series (the graphitic cast-irons*), the members of which are simply the steel or the white cast-iron (as the case may be) of the graphite-less series, plus graphite.

---

* Strictly speaking, any high-carbon steels and any cast-irons which, in spite of having a white fracture, yet contain a really important quantity of graphite, belong here; but for the purposes of our bird's-eye view we may neglect them.

Let us consider first the graphite-less series, the simpler because the influence of the ferrite and cementite is not here obscured by that of graphite.

If we plot a great number of cases, with carbon as abscissæ and tensile strength, ductility and hardness as ordinates, as in Fig. 1,* we find that, whereas the ductility diminishes and the hardness increases continuously as the carbon increases, the tensile strength increases only until the carbon reaches about 1 per cent., when it reaches a maximum, and then in turn decreases. This law we may regard as firmly established for steel under normal conditions. The reason for the general features of these curves will be discussed in Section III.

Let us now turn to the graphitic series, which includes both gray and mottled cast-iron, and let us consider first (A) cases in which the graphite is constant and the combined carbon varies; then (B) those in which combined carbon is constant and graphite varies; and then in II. those in which both vary.

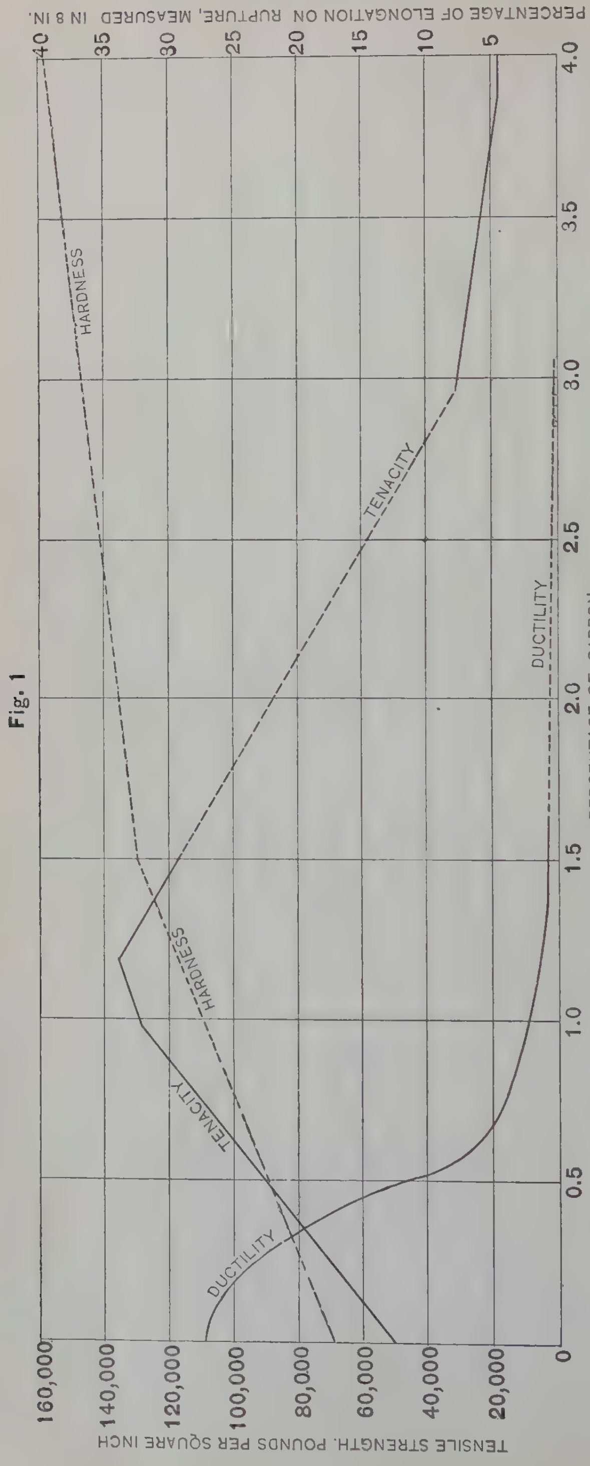
A. *Graphite Constant, Combined Carbon Varies.*—Here, since variations in the combined carbon, *i.e.*, in the carbon of the matrix, should cause the same effects in that matrix as similar carbon-changes cause in steel, therefore, as the combined carbon increases the hardness of the mass as a whole should increase, and its ductility should decrease—in both cases continuously. But the tenacity of the matrix, and through it the tenacity of the conglomerate whole, should increase until the combined carbon reaches about 1 per cent., and should in turn decrease as the combined carbon further increases.

B. *Combined Carbon Constant, Graphite Varies.*—The graphite by itself should weaken, soften and embrittle cast-iron. Scattering through the metal sheets of a weak substance like graphite should in effect break up the continuity of the mass, and this should both weaken and embrittle the mass as a whole; and it should soften the mass somewhat, because graphite itself is so soft. Hence as the graphite increases the strength, ductility and hardness should all decrease continuously.

---

* We have no sufficient quantitative data to enable us to plot the hardness-curve. That given in Fig. 1 is simply sketched in by eye, to show the results of general observation; and the dotted parts of the tenacity- and ductility-curves make no pretence whatever to quantitative accuracy, but are simply conjectured as the result of general observation.

Fig. 1



TENACITY, DUCTILITY AND HARDNESS OF IRON, AS AFFECTED BY THE PERCENTAGE OF CARBON.

(The position of the parts of these curves which appear in broken lines is conjectural.)

II. Commercial Foundry Pig-Irons.

The total carbon of these pig-irons as they run from the blast-furnace usually varies relatively little, so that as the combined carbon increases, graphite usually decreases. That is, one is in general approximately the complement of the other. For the sake of simplicity and definiteness, we will through the present section consider the influence of variations in the combined carbon in a series of cast-irons all containing exactly 4 per cent. of total carbon, and to fix our ideas we will consider the influence of a progressive increase in the combined-carbon content. Such an increase has a two-fold aspect, the progressive increase in the cementite-content of the matrix, and the complementary decrease in the quantity of the foreign body, graphite.

Tensile Strength.—Starting with combined carbon at zero and graphite 4 per cent., we must have a very weak cast-iron; for its matrix is essentially ferrite, the weakest member of the ferrite-cementite series in the steels, mixed with the maximum quantity of graphite, in itself a most weakening substance.

As the combined carbon progressively increases from zero up to one per cent., the tenacity should increase continuously for a double reason: (1) the matrix is growing stronger and stronger because it is growing richer and richer in carbon, passing from the softest and weakest steels through the structural steels up to the tool-steels and those which yield the strongest plough-steel wire (see Fig. 1); while (2) at the same time the proportion of graphite, in itself a weakening substance, is growing less and less. So far all is simple.

But as the combined carbon increases beyond one per cent. the case is less simple, for our two influences now oppose each other. The matrix is growing weaker as its carbon rises above one per cent. (see Fig. 1); but the simultaneous decrease in the proportion of graphite present is strengthening the mass as a whole, simply by lessening the amount of this weakening substance. So in the range lying between 1 and 4 per cent. of combined carbon, *i.e.*, between 3 per cent. and zero of graphite, we cannot tell from these synthetic data where the strongest cast-iron will be found.

Hardness.—As regards hardness the case is most simple. We find in the steel-to-white-cast-iron series that the hardness in-

creases progressively and without limit as the carbon increases; indeed it could hardly be otherwise, for we can hardly understand how progressively replacing a copper-like substance, ferrite, with a glass-hard one, cementite, should fail to increase the hardness progressively. Hence (returning to our present series of cast-irons with 4 per cent. total carbon, and progressively increasing combined carbon) the hardness of the matrix should increase continuously as the combined-carbon content increases; and the corresponding decrease in the quantity of so soft a substance as graphite should in itself progressively harden the conglomerate as a whole. In short, in both its aspects the progressive transfer of carbon from the graphitic to the combined state should increase the hardness of the whole.

Ductility.—As a little reflection shows, the decrease in the ductility, like the increase in the hardness, should be continuous as the combined carbon increases from zero to four per cent. In the steel-to-white-cast-iron series, as the carbon increases, the very brittle cementite progressively replaces the ductile ferrite, a change which certainly must lessen ductility continuously; and this effect should take place likewise in the matrix of our present series, our graphitic cast-iron; and, while the simultaneous decrease of graphite should in itself tend to increase the ductility by lessening the quantity of this continuity-destroying substance, yet this effect should be less than that of the increase of cementite in the matrix. For the change of one per cent. of carbon from the graphitic to the combined state simply lessens the quantity of graphite present by one per cent.; but it increases the quantity of the very brittle cementite by 15 per cent., and the loss of ductility due to this feature of the change certainly should outweigh the gain of ductility due to removing one per cent. of graphite.

Indeed, we may note in passing that, in general, a given change in the combined-carbon content should have a far greater effect on the hardness and ductility than a like or opposite change in the quantity of graphite. Suppose that, by introducing silicon or otherwise, without changing the total carbon, we increase the graphite by 2 per cent., thereby lessening the combined carbon by 2 per cent. and the cementite by 30 per cent. Now while we cannot understand how the introduction of 2 per cent. of a foreign substance like graphite, in

thin flakes somewhat widely scattered, can make the grains of iron between those flakes much more malleable, much easier to machine, much softer under the file or under the diamond; yet we readily understand how removing from the matrix of the iron 30 per cent. of a glass-hard substance like cementite, which has been scattered through the whole mass in microscopic particles,—most intimately mixed, flesh of its flesh,—and replacing it chiefly by the soft ductile ferrite, should greatly lessen the hardness and brittleness of the mass.

But this of course does not imply that the same holds true of tensile strength, because the influence of combined carbon on this property is not constant, but reverses when the combined-carbon content rises past one per cent.

III. Explanation of the Influence of Carbon on the Physical Properties of Cast-Iron.

Hardness and Ductility.—As any increase in combined carbon in effect substitutes the glass-hard extremely brittle cementite for the soft, ductile, copper-like ferrite, the continuous increase of the hardness and the continuous decrease of ductility as the carbon increases need no further explanation.

Tenacity.—In order to understand this much less simple case, we may well consider the usual mode of arrangement of the ferrite and cementite. In any individual steel these two substances habitually interstratify in thin sheets, in the ratio of about 7 parts of ferrite by weight to one of cementite; and the composite mass or conglomerate thus formed is called pearlite. As cementite contains 6.67 per cent. of carbon, and as the ratio in which it interstratifies with ferrite is about 1 : 7, it follows that pearlite must contain about $\frac{6.67}{7+1} = 0.83$ per cent. of carbon. It is a true eutectic; the two substances, ferrite and cementite, which compose it, though present in nearly constant proportions, are wholly separate and distinct from each other, quite as the grains of quartz, feldspar and mica are in a granite. Nevertheless, since though composite it is of constant composition, it is convenient to treat it as a distinct entity.

If the steel as a whole contains 0.83 per cent. of carbon, *i.e.* $\frac{0.83 \times 100}{6.67} = 12.5$ per cent. of cementite, so that the fer-

rite (which must form the remainder of the mass, and therefore amount to 100 — 12.5 = 87.5 per cent.) stands to the cementite in the ratio of 7 : 1, then all the ferrite and all the cementite usually interstratify to form pearlite, during slow cooling.

If there be more than 0.83 per cent. of combined carbon there will be more than 1 of cementite to 7 of ferrite, *i.e.*, more cementite than can interstratify with the ferrite present in its fixed 7 : 1 ratio to form pearltite; and, as happens in all eutectiferous masses, the excess of cementite simply separates out within the mass as distinct "free," "massive" or "structurally free" cementite; so that steel containing more than 0.83 per cent. of carbon consists of pearlite plus free cementite. It is "hyper-eutectic" steel.

If, however, the steel contains less than 0.83 per cent. of carbon, and hence less than 12.5 per cent. of cementite, *i.e.*, less than is needed to form pearlite with the whole of the ferrite present, there will now be an excess of ferrite over and above that which can unite with the cementite present in the fixed ratio 7 : 1; and this excess will separate out within the mass, in the form of "massive" or "structurally free" ferrite. The steel is "hypo-eutectic."

To recapitulate, while steel consists essentially of ferrite mixed with cementite, the latter increasing with the carbon in the ratio of 15 per cent. of cementite to every 1 per cent. of carbon, these two components usually interstratify in the ratio of 7 : 1 to form pearlite. Hence steel consists either of pearlite alone, or of pearlite mixed granitically with the excess of either ferrite or cementite, according to whether it contains 0.83 per cent., or less, or more, than that quantity. The same is probably true (*mutatis mutandis*) of the "matrix" in cast-iron.

While the existence of this special mode of arrangement of the ferrite and cementite does not disturb our inference that every increase of combined carbon, and hence of cementite, must increase the hardness and lessen the ductility of the mass taken as a whole, yet it may well have a very marked influence on the relation between carbon-content and tensile strength.

When two substances differing as greatly as ferrite and cementite in hardness, strength and ductility, are thus intermixed, it is indeed not easy at first to predict how they will behave under stress. But we can understand that the particles

of each must bear a share of the stress and transmit it to their neighbors. One of them, ferrite, flows under stress, and is strengthened by this flow, as the strengthening effect of wire-drawing, cold-rolling, and all other forms of permanent distortion of low-carbon steel and wrought-iron testifies; the other, cementite, appears to be absolutely rigid and non-ductile. We can understand that they should behave under tensile stress like distinct entities, because of the wide difference in their properties; and that, in a way and within limits, the cementite should mechanically support the ferrite and prevent its excessive flow and ready yielding. For we must recollect that the mixture of the two is very intimate. Not only are the ferrite and cementite which interstratify to form pearlite most intimately mixed, but the excess of ferrite is penetrated by the pearlite, which dowels its particles together.

But even in view of these conditions, the increase of tensile strength caused by carbon seems in some cases too great to be readily explained by this purely mechanical action of cementite. For instance, in steel containing 0.21 per cent. of total carbon,* the cementite is contained partly in a network of pearlite and partly in some plums of pearlite swimming in the matrix of ferrite. That the network, usually very thin and probably often discontinuous, should have a material strengthening effect is certainly not self-evident; that the plums, widely separated from each other as they are, should have such an effect is even less evident. In passing these islands rupture should follow the path of least resistance, around them and through the matrix of ferrite; and this path should not be very greatly lengthened by having to pass around these islands. Indeed, the pearlite rather suggests strong links set ineffectively among the weaker ones of a chain of ferrite, and adding nothing to the general strength. Yet such steel is nearly 50 per cent. stronger than pure ferrite, as we find it in the most nearly carbon-less iron. So, too, in steel of 0.14 per cent. of carbon,† the cementite present is contained in a network of pearlite, apparently so very thin and so much broken up that we hesitate

---

* See Mr. Sauveur's sketch of such steel when slowly cooled, *Trans.*, xxvi., 863, Pl. I., Fig. 7.

† See Osmond, *Méthode Générale pour l'Analyse Micrographique*, Figs. 101 and 162; also Sauveur, *op. cit.*, Pl. III., Fig. 4.

to ascribe to it any great strengthening-effect. Further, the increase of tensile strength which accompanies progressive increase in carbon-content seems at first too regular to be accounted for fully by the corresponding but varying changes which occur in the mode of distribution of the pearlite. Hence, while it is wholly possible that this mechanical explanation really covers the chief or sole cause of the strengthening-effect of carbon, yet its lack of cogency leads us to seek some contributory cause. And such a cause I now suggest, drawn from an obvious extension of the allotropic theory. It is clear that, above the critical temperature Ac_2, the iron itself becomes allotropic; and one of the prominent theories of the hardening of steel is that the sudden cooling preserves this high-temperature allotropic iron, by denying the time required for its change back to the normal state—that during slow cooling this allotropic iron changes back to normal iron; but that if the steel be cooled very suddenly there is not time enough for this reverse change to occur, and we thus retain in the cold steel the allotropic iron, of which one variety (β) is intensely hard and brittle, and the other (γ) is harder and stronger than normal or α iron. In order to explain the facts, it has been found necessary to assume that the carbon present in the steel acts as a brake to retard this reverse change from allotropic to normal iron; hence the hardening of high-carbon steel, in which, thanks to this brake-action, the allotropic iron is preserved in sudden cooling; hence also the non-hardening of low-carbon steel, in which even sudden cooling, lacking the brake-action of the carbon, fails to retain the allotropic iron.

Now, I would invoke this brake-action to help explain the increase of tenacity of even slowly cooled steel which accompanies the increase of carbon from zero towards one per cent. A late study of the magnetic properties of steel led me to suppose that, even with slow cooling, an appreciable quantity of allotropic iron remained in the cold metal, without changing back to normal iron. It may well be that this brake-action of carbon applies to a limited extent even to slow cooling; and hence that in the ferrite even of slowly cooled steel there should be present some of the hard, strong, allotropic iron, and that the proportion of this, and hence the tensile strength of the conglomerate whole, should increase with the carbon-content.

The same assumption would give an additional explanation of the increase of hardness and decrease of ductility caused by carbon.

We thus have two explanations of the increase of tenacity as the carbon increases from zero towards one per cent., either or more likely both of which may be true.

Of the reversal of this curve, and the decrease of the tenacity as the carbon rises beyond one per cent., the microstructure offers a reasonable explanation. Until the carbon reaches 0.83 per cent. the cementite usually exists in minute sheets as part of the pearlite; and though when the carbon first rises beyond 0.83 per cent. there is a little free cementite not included in the pearlite, this free cementite is in small and discontinuous particles. As the carbon increases still farther, the excess of free cementite rapidly increases, forming thicker and thicker masses, tending to form a continuous skeleton or network.

Thus, among Roberts-Austen's Brymbo steels,* those containing 1.461 per cent. and 1.38 per cent. of carbon respectively already have the cementite in a continuous skeleton, encircling the polyhedrons of pearlite; and one containing 1.80 per cent. of carbon has the cementite in a like skeleton, but much thicker. Indeed, a continuous skeleton of cementite is shown by Mr. Sauveur† in a steel containing only 1.20 per cent. of carbon.

Now we can readily understand that, so long as the free or "excess" cementite is in discontinuous minute particles, each of which is suspended in the pearlite and free to move in it as in a menstruum, the cementite should strengthen the mass, for instance by opposing its tendency to flow. At the same time we can understand that, when the cementite had reached such proportions that it formed a considerable continuous skeleton, or relatively thick sheets, the fact that these can no longer accommodate themselves to the yielding and flow of the pearlite would concentrate upon them an undue part of the stress. The consequence of this might well be that, being unyielding, non-ductile, they break under this undue stress, and that the fine cracks, the solutions of continuity, thus set up would lead to

* Fifth Report to the Alloys Research Committee, Figs. 43 and 45, Plate XI., and Fig. 99, Plate XXI.

† *Trans.*, xxvi., 878, and Plate I., Fig. 14.

the break-down of the mass as a whole. The more of this free cementite there is, within limits, the greater this tendency towards the break-down of the mass as a whole, through the starting, in the unyielding cementite, of cracks sufficiently important to spread rupture.

In some such way we can readily understand both the increase of tenacity as the carbon rises to 0.83 per cent. and its decrease as the carbon in turn rises beyond, say, 1 per cent.

IV. What will the Strongest Cast-Iron Be?

This fact, that the strongest iron-carbon compound is steel with about one per cent. of carbon, and that the tenacity decreases as the carbon either decreases or increases from one per cent., leads us to suppose that the less total carbon cast-iron contains, the stronger can it be made, and that one important line of progress will be the production of cast-iron castings lower in carbon than our present ones.* I purposely say "can it be made," because the strength depends not only on the total carbon but on its distribution between the states of graphite and cementite, as determined by the quantity of silicon, manganese and sulphur present, by the casting-temperature, the thickness of the casting, and other things which influence the rate of cooling, etc., etc. For every percentage of total carbon, however, there is a "best proportion" for this distribution, a proportion which yields greater tenacity than any other proportion for that particular total percentage. Hence my thesis is that, "the lower the total carbon, the stronger should the cast-iron 'of best proportion' be." This is a proposition to which I ask careful attention. On turning it over and over I find no escape from it as a reasonable probability. Certainly if to steel of one per cent. of carbon we add combined carbon, the tenacity curve of Fig. 1 shows that we weaken it; the addition of graphite, which is a weak, foreign, continuity-destroying body, ought to weaken it; if we add both combined carbon and graphite, the latter, as before, should

* I am well aware that some who ought to know hold the opposite opinion. One prominent writer asserts "that the strongest and most ductile cast-iron is that which contains a maximum of carbon . . . ." (*The Iron Trade Review*, Oct. 4, 1900.) It is not in spite of their opinion, but because of it, that this paper is written.

weaken it, and the former, by adding carbon to the metallic matrix, should, according to Fig. 1, weaken that matrix, and thus weaken the conglomerate mass. And if every addition of carbon in excess of one per cent. weakens, every reduction towards one per cent. should strengthen, always assuming that in each case the carbon is distributed in the "best proportion." The "best proportion" for one per cent. of total carbon is: combined carbon 1 per cent.; graphite, zero. It is hard to escape the conclusion that for every increase of the total carbon beyond one per cent. the best proportion must yield a weaker conglomerate; for if this new best proportion changes the combined carbon, it must carry the matrix away from the maximum-strength carbon-content of one per cent.; and if it increase the graphite, that in and by itself should be a weakening change. And, as before, if every increment weaken, every decrement should strengthen.

I fail to conceive any definite case in which the opposite effect is to be expected. Perhaps the case in which this hypothesis seems most likely to fail is one in which the change from the "best proportion" for a given total carbon-content to the "best proportion" for a lower one takes place through a relatively large decrement of combined carbon which is initially below one per cent., and a simultaneous smaller increment of graphite. Such a decrement of total carbon should be weakening, since both the steps which compose it are in themselves weakening. But it is hard to believe that such a condition of affairs can exist. That the assumed initial distribution can have been "of best proportion" is hard to believe, because, while denying to the matrix the one per cent. of carbon which would give it the greatest strength, it liberates, in the directly weakening form of graphite, the carbon thus denied to the matrix. And, if we assume that this initial distribution was "of best proportion," it is for like reasons difficult to suppose that these steps could lead from an initial to a final "best proportion."

The verification of such a hypothesis must be extremely difficult, owing to the number and importance of the other variables. Even if these were eliminated, verification or disproof would probably need, as a first condition, that we learn what is the "best proportion" for different percentages of total carbon, *i.e.*, the "law of the best proportion."

It will probably be extremely easy to present an enormous quantity of evidence which at first sight opposes this hypothesis, but which, like that of Mr. Keep, discussed in Section V., is wholly incompetent, either because of our ignorance as to the law of the "best proportion," or for other reason.

I have no cogent evidence for or against this hypothesis; I present it for others better placed to test. There is, however, a consideration which, though it certainly is not cogent evidence, may well be presented here as an aid to any who may attempt a more thorough verification of the present hypothesis. It is that two of the most excellent classes of cast-iron, air-furnace castings* and charcoal cast-iron, are just those likely to be particularly poor in total carbon.

The cupola-furnace is a carburizing apparatus, the air-furnace a decarburizing one. If the iron when first melted in the cupola is low in carbon, whether from the use of low-carbon cast-iron or even of steel scrap,† or from decarburization in

* I take this occasion to record an important bit of evidence as to the superiority of air-furnace over cupola-castings made under closely like conditions. Mr. William Metcalf, writing of his priceless experience in the manufacture of cast-iron guns and projectiles at the Fort Pitt Foundry in Pittsburg, during the War of the Rebellion, says: "During the rush of the war we melted all of our projectile iron in large cupolas, every pound of our reverberatory capacity being required for guns. We used for shot and shell, good Hanging Rock, Iron Mountain and some Pennsylvania charcoal irons, and no scrap except our own projectile scrap. General Rodman was always . . . . demanding 25,000 lbs. tenacity in projectiles, but we could not get it from the cupola without using gun-iron, of which we had not a pound to spare. Finally, when the rush was over, he laid down the law, all projectile iron must be over 25,000 lbs. We then calculated that it was cheaper to melt our projectile iron in reverberatories than to melt gun iron in the cupolas, so we shut down the cupolas and melted our projectiles in the reverberatories. There was no change whatever in the irons; the only change was in the melting. The cupola projectiles averaged 22,000 to 23,000 lbs. tenacity; the reverberatory projectiles averaged 26,000 to 28,000 lbs., a clear gain of about 4000 lbs., or, say, from 3 to 5000 lbs. Why? I do not think sulphur and dirt from the coal had any more influence than the air; I believe oxygen and nitrogen blown through the iron in the cupola do as much harm as the sulphur, probably more." (Private communication, November 26, 1900.)

The nitrogen and hydrogen blown across the iron in the cupola might well be harmful; but it is not so easy to suppose that the atmospheric oxygen should affect so highly carburetted a body as cast-iron, except by oxidizing and removing its carbon, silicon, etc.

† Ledebur points out that steel and malleable iron melted in a cupola are thereby necessarily converted into cast-iron. (*Eisen- und Stahl-giesserei*, 1892, p. 144.) On remelting pig-iron in a cupola six times, Jungst found that the total carbon rose on the first fusion from 3.10 to 3.33 per cent., and remained practically

front of the tuyeres, it greedily absorbs carbon as it runs across and through the column of incandescent coke, which stretches down through the zone of fusion and rests on the very bottom of the furnace. Those who have seen the almost instantaneous carburization of molten steel by Darby's process will recognize how powerfully carburizing the conditions in the bottom of the cupola must be. Indeed, our wonder rather is why cupola castings, and indeed all cast-iron as it issues from the blast-furnace, are not nearly saturated with carbon.

In the air-furnace, however, not only can the metal gain no carbon, but it must lose some, and it may lose much. I do not find many analyses which are explicitly given as representing air-furnace castings, but the following statements are of interest. Mr. T. Ulke reports* the average total carbon-content of 15 air-furnace gun-irons as 3.03 per cent. Mr. C. H. Vannier reports:† "With equivalent mixtures I find air-furnace metal to carry, in round numbers, 3 per cent. carbon, against 3.5 per cent. in cupola metal." Dr. Richard Moldenke gives the following as a typical analysis of fine gray air-furnace castings, together with the usual range of composition of such castings:‡

---

constant thereafter. Manganese was removed rapidly at first, then more slowly; silicon was progressively removed after the first melting. So, too, the carbon-content of three pig-irons, each containing initially more than 4 per cent. of carbon, and each remelted by Ledebur separately in a cupola four times, fell in the first (or first two) fusions to about 3.50, and thereafter varied little, sometimes increasing, sometimes decreasing. (*Das Roheisen*, 1891, pp. 72–3.)

* *The Iron Trade Review*, Dec. 1, 1898, p. 8. † *Id.*, Oct. 25, 1900.

‡ Private communication, Nov. 24, 1900. It is proper to refer here to the many analyses of cast-iron guns, which I confidently believe were cast from the air-furnace, recorded in the "Reports of Experiments on Metals for Cannon," 1856. In the "Final Report" on composition are given thirty-two analyses of such iron, with the total carbon varying between 2.60 and 4.60 per cent., and averaging 3.72 per cent. The results of this monumental work thus seem at first to strike at the root of my evidence, by showing that air-furnace castings are habitually rich, and may be very rich, in carbon. But after careful examination I must reject these results as certainly unworthy of consideration. In this final report we find that one gun, which endured 111 service rounds, contained 5.21 per cent. of manganese; and, in spite of having only 2 per cent. of silicon, it yet incongruously contained 2.80 per cent. of graphite. One gun contained 0.23 per cent. of calcium, and another 0.69 per cent. of aluminum. A previous report in the same volume, by the same chemists, gives most of the guns as containing over 6 per cent. of manganese; two of them had nearly 16 per cent., and one of them 18 per cent. of that element. One had 3.46 per cent. of aluminum;

	From Per cent.	To Per cent.	Typical Composition. Per cent.
Total carbon,	2.75	3.25	2.81
Silicon,	1.90	2.40	2.09
Manganese,	.40	.80	.47
Phosphorus,	.25	.60	.523
Sulphur,	.02	.05	.045

The upper limit for carbon in air-furnace castings here given is approximately the lower limit for common cupola castings, according to my observation. Looking through a large number of analyses of such castings I find only three with less than 3.11 per cent. of total carbon, and some with over 4 per cent. In a group of 75 analyses of car-wheels, presumably made of cupola cast-iron, all but four have at least 3.30 per cent. of total carbon. Ledebur, while admitting the decarburization in the air-furnace, thinks that not more than one-sixth of the total carbon is thus removed.*

It is true that the cupola can be managed so as to decarburize materially, by cutting down the coke, and thus doing a considerable amount of Bessemerizing. Thus Mr. Ulke† even reports that the cupola gun-iron of the Niles Tool-Works contains from 2.4 to 2.6 per cent. of total carbon; and, on the authority of S. S. Knight, that certain cast-iron of the Rarig Engineering Works (improperly called "semi-steel"), made by melting pig-iron with a very large addition of boiler-plate scrap

two had more than 6 per cent. of phosphorus. Average results of a whole class of iron gave 14.84 per cent. of carbon. The graphite in one specimen was 16.25 per cent. In the light of our present knowledge these results, which referred to cast-iron guns of high quality, are absurd: the data as to carbon-content rest on the same basis of authority, and hence deserve no weight. That such conscientious work should have led to such gross errors is hard to understand, even in view of the time when it was done. One at first wonders whether one reads aright, especially in view of the confusing way of reporting the composition, not in percentages but in fractions of unity; but I am confident that these errors cannot thus be explained away.

* *Eisen- und Stahlgeisserei*, 1892, p. 101. He indeed asserts that if the temperature be purposely kept low, and sufficient manganese and silicon be present, the removal of carbon can be wholly prevented; but his warrant for this, viz., the occasional lack of decarburization in the melting down of the puddling process (*id.*, p. 100), is hardly sufficient, first, because of the difficulty of accurate sampling under these conditions, and, secondly, because the basic puddling slag leads to the preferential removal of silicon instead of carbon, to a degree not to be expected with the acid slag of the air-furnace, as used for cast-iron.

† *Loc. cit.*

in a cupola, contains 1.71 per cent. of total carbon. But this fact, instead of weakening the force of our present consideration, supports our hypothesis. For our present consideration is based on the superiority of air-furnace castings over common, *i.e.*, high-carbon, cupola castings; and the fact that when, by special steps, cupola-castings are made low in carbon they are exceptionally strong, is just what our hypothesis calls for. Thus the Niles Tool-Works gun-iron, just referred to, had a tenacity of 28,000 to 37,000 lbs. per sq. in., with an elongation of 0.50 to 0.60 per cent.; and the Rarig cast-iron had a tenacity of 33,680 to 35,730 lbs. per sq. in.

So, too, another excellent class of cast-iron, namely, charcoal-iron, has as a whole less carbon than the classes of coke-iron comparable with it, *i.e.* low-sulphur foundry-iron; though I must admit that the force of this fact is greatly lessened by the large proportion of exceptions to the rule. The argument is as follows:

If we assume that the carbon-distribution of charcoal-irons as a class is as near the "best proportion" as that of coke-irons as a class, the fact that charcoal-irons as a class are stronger, and also contain less total carbon than coke-irons as a class, is consistent with the hypothesis that low carbon in cast-iron makes for tenacity. That fact is, of course, explicable on other grounds also; this can, therefore, at best be but corroborative evidence. If it should be found that the high-carbon charcoal-irons are as strong as the low-carbon ones, the fact would oppose the present hypothesis.

Let me present evidence as to the usual lower total-carbon content of charcoal- than of comparable coke-irons.

On plotting the composition of many hundred pig-irons, the majority of which were coke- or anthracite-irons, I found the total-carbon generally above 3.50 per cent., and in a very large proportion of cases between 3.75 and 4.25 per cent.*

In a series of 225 coke pig-irons and 66 charcoal ones, 37 per cent. of the charcoal-irons and only 14 per cent. of the coke-irons have less than 3.25 per cent. of carbon, while 16 per cent. of the charcoal-irons and only 4 per cent. of the coke-irons have less than 3.00 per cent. carbon.†

* "The Influence of Silicon and Sulphur on the Condition of Carbon in Cast-Iron," *Trans.*, xxx., 719, Fig. 1 (p. 724).

† *Analyses of Pig-Iron*, by S. R. Church.

Among 30 coke and anthracite foundry-irons and 16 charcoal-irons, 44 per cent. of the charcoal-irons have 3.19 per cent. carbon or less, against only 17 per cent. of the coke-irons.*

Among 18 coke- or anthracite-irons (ferro-silicons and irons with 3.5 per cent. silicon excluded) and 18 charcoal-irons, 61 per cent. of the charcoal-irons and only 28 per cent. of the coke-irons have 3.50 per cent. carbon or less; and 39 per cent. of the charcoal-irons, against only 17 per cent. of the coke-irons, have 3.19 per cent. carbon or less.†

In a group of 27 charcoal pig-irons 13 have less than 3.50 per cent. of carbon.‡

In a group of seven analyses of charcoal pig-iron, 5 have less than 3.50 and 3 have less than 2.90 per cent. of carbon.§

That charcoal pig-iron should contain less carbon than coke-foundry, *i.e.* low-sulphur, pig-iron, is natural. In coke-furnaces the removal of the sulphur introduced by the coke requires that the slag be very calcareous; calcareous slags have a very high melting-point; hence the temperature must be extremely high so as to melt them. In short, the coke-furnace needs an especially high temperature in order that it may desulphurize. Charcoal-furnaces, at least when treating low-sulphur ores, have not this need, because, thanks to the freedom of the charcoal itself from sulphur, they need not desulphurize. Now, the especially high temperature may well lead to especially high carburization, since the solvent power for carbon may be expected to rise with the temperature.

An observation which is very suggestive in this connection is that, while charcoal pig-iron yields excellent castings when melted in the air-furnace, its superiority diminishes, or even disappears, if it be remelted in the cupola. Now, in so far as the initial superiority of charcoal-iron is due to its freedom from sulphur, that superiority should persist after cupola-fusion; for both coke and charcoal irons in such remelting should absorb sulphur about equally, so that the relative merit of charcoal-iron should remain. So of the removal of silicon. The loss of superiority on cupola-fusion, then, being insuffi-

* Vosmaer, *Iron and Steel*, pp. 172–175.

† Ledebur, *Eisenhüttenkunde*, 1889, pp. 377–379.

‡ Henderson and Davis, *American Engineer and Railroad Journal*, Jan. 1, 1899.

§ *Report of the Tests of Metals*, Watertown Arsenal, 1899, p. 369.

ciently explained by absorption of sulphur, or removal of silicon, must have a further explanation; and one is supplied by the present hypothesis. For if the usual initial low carbon of charcoal-iron is really one cause of its superiority, this cause ought to disappear on cupola-fusion, since the carburizing action of the cupola ought to make the final carbon of castings made from charcoal-iron substantially the same as that of coke-iron castings. This phenomenon of the loss of superiority of charcoal-iron or cupola-fusion, then, is inexplicable on the hypothesis that that superiority is due solely to low sulphur, or silicon, or both, but is consistent with the hypothesis that it is due in part to low carbon-content.

In this view the capital defect of the iron blast-furnace, as an instrument for making foundry cast-iron, is that it nearly saturates the iron with carbon, or at least gives it far more carbon than is consistent with the greatest strength, or the greatest combination of strength with ductility. It is hard to see how this fault is to be remedied within the furnace itself when the fuel is coke, since the desulphurizing action of the furnace, which cannot be dispensed with, is apparently part of the carburizing action. Both apparently take place in the crucible of the furnace, and both depend upon the same conditions, viz., that the bath of molten iron in the crucible is penetrated by a solid column of incandescent coke, with the carbon of which the molten iron rapidly saturates itself fully, or almost fully. This same carbon removes the sulphur from the iron, apparently, by the reaction

$$FeS + x\,CaO, SiO_2 + C = Fe + CaS + CO + (x - 1)\,CaO, SiO_2.$$

So, too, in this view, the capital defect of the cupola-furnace, as an instrument for making strong castings, is that the molten iron in like manner greedily absorbs carbon from the fuel over which it runs at the bottom of the furnace; so that, no matter how little carbon the charge contains initially, as it issues from the cupola it is over-rich in carbon.

To sum this discussion up, the hypothesis, that, assuming the carbon to be distributed in "the best proportion" between the states of cementite and graphite, then the lower the total-carbon the greater will be the strength, is in itself reasonable,

and derives color from the fact that two of the best classes of cast-iron, charcoal cast-iron and air-furnace castings, are just those with habitually low-carbon content; and while this excellence is wholly explicable by other causes, which, indeed, doubtless do contribute to it, yet the loss of excellence of charcoal cast-iron on cupola-remelting is not readily explicable by these other causes, but is wholly in harmony with our hypothesis. This hypothesis, then, is offered tentatively, as worthy of further test by comparison with observed facts.

V. Remarks on Current Opinions Regarding Cast-Iron.

The notion that the addition of ferro-silicon increases the quantity of scrap which a cupola-charge can carry has been ridiculed. This, I think, is unfair. The proposition may or may not be found actually true in practice. My understanding is that it has been found true. But whether actually true or false, it is not ridiculous, but on the contrary eminently reasonable. When scrap-iron is melted in the cupola-furnace it tends to lose silicon without correspondingly losing carbon, for the simple reason that, while the silicon which is burnt away as the iron drops past the tuyeres cannot be readily restored in the cupola, the carbon simultaneously burnt away is so restored, as has been explained in Section IV.

Now the removal of the silicon tends to diminish the graphite in the resultant casting, and thereby to increase the quantity of combined carbon; thereby to increase the cementite; and thereby to make the resultant castings harder and more brittle. The addition of ferro-silicon raises the silicon in the castings; thereby increases the graphite; and thereby diminishes the combined carbon. Or, it is probably more accurate to say that the addition of ferro-silicon diminishes the amount of combined carbon by lowering the solvent power of the solidifying iron for carbon, thus forcing part of the carbon out of combination into the form of graphite, and this reduction of the amount of cementite, or of combined carbon, softens the castings. One would naturally suppose that even a charge of scrap cast-iron alone could readily be converted in good gray castings by the addition of a sufficient amount of ferro-silicon. Such a charge of scrap, when melted, would in any event have sufficient carbon to make it brittle and intensely hard, provided no silicon at all

were present. The addition of ferro-silicon should diminish the combined carbon in such castings, and this itself would make the castings softer.

The confusion, I think, arises from the notion that it is the graphite itself which chiefly affects the hardness of the castings; whereas it is the combined carbon which affects the hardness of the castings chiefly, and the presence of much graphite is simply a sign that the combined carbon is correspondingly low. You cannot eat your cake and keep it; and carbon which has separated as graphite can no longer remain in combination as cementite to harden and embrittle the metal.

Mr. W. J. Keep* finds "*the most conclusive proof that the existence of combined carbon has no influence, unless to weaken a casting by making it brittle*," and as regards graphite, that "*strength or weakness seem to be absolutely independent of this element.*" These inferences he draws from a great number of cast-irons varying but little in total carbon. In such a series, as the combined carbon increases, the graphite must decrease; so if both the combined carbon (in excess of 1 per cent.) and the graphite weaken and embrittle the cast-iron, the effect of the increase of one in such a series as his might be masked by the effect of the simultaneous decrease of the other. Thus one might very readily be led to Mr. Keep's conclusions, and fail to note that they are probably true only for approximately constant total-carbon. While it may be true that, for any given percentage of total carbon, as in his data, variations in the condition of that carbon have relatively little influence (the state of cementite injuring the strength about as much as that of graphite), this is no evidence that each of these substances by itself is harmless. It would be about as logical to infer that neither graphite nor combined carbon weighed anything, because changing carbon from one state to the other did not affect the weight of the cast-iron as a whole, as to infer that neither separately affected the strength or ductility, from the fact that shifting the carbon from one state to the other does not greatly affect those properties. The resultant of two equal and opposite forces, no matter how powerful, is zero.

* *Trans. Am. Soc. Mech. Engrs.*, xvi., pp. 1103-4, 1895.

The Use of the Tri-Axial Diagram in the Calculation of Slags.

BY PROF. ERNEST A. HERSAM, BERKELEY, CAL.

(Richmond Meeting, February, 1901.)

THE advantages of the tri-axial diagram in representing the composition of slags and silicates are well appreciated by many metallurgists. Prof. H. M. Howe* has pointed out the application of a fourth variable, in connection with the diagram, and has called attention to the usefulness of the general system of tri-axial representation. In the discussion of Prof. Howe's paper, Mr. Firmstone† indicated how certain distances could be measured directly by projection.

Prof. R. H. Thurston,‡ as early as 1877, had made use of a glyptic model and of triangular diagrams, with contour-lines, representing varying physical properties corresponding to varying chemical composition. Still earlier, Prof. J. Willard Gibbs§ had used the diagram in similar work; and other scientists were thought by him to have preceded him in its use.

During the period of nearly a quarter-century, following these early publications, there has been an ever-increasing use of graphic methods in numerous branches of scientific work, stimulated, in part, by the possibility of representation by three co-ordinates upon plane-surfaces. Yet the number of possible co-ordinates for graphic representation has always been, and always must be, insufficient to express many facts which are shown mathematically; while, without graphic representation, the involved nature of mathematical expression often fails to facilitate and promote research. The coming into use, therefore, of the fourth co-ordinate, permitting representation by four variables, marks but the beginning of some lines of research which could not well advance without this aid.

---

* *Trans.*, xxviii., 346. † *Id.*, xxviii., 899.
‡ *Proc. A. A. A. S.*, 1877. § *Trans. Conn. Acad.*, 1876, vol. iii., p. 176.

Aside from the tri-axial diagram, various systems have been employed for the graphic representation of three variables. These systems, mostly ingenious, and suited to the purposes for which they were employed, are outside the field of work under consideration here. Reference may be made to a paper by H. W. Bakhuis Roozeboom* and also to one entitled "A Triangular Diagram," by Prof. Wilder D. Bancroft,† in which, together with descriptions of the tri-axial diagram, some other diagrammatic methods are discussed.

In using the tri-axial diagram for some purposes, one finds it helpful to extend the application, in certain ways, to a point beyond that which hitherto has been the limit. When one plots upon the diagram, for example, in the usual manner, for metallurgical purposes, ores, flux, and a slag to be produced therefrom, one obtains a clear presentation of the mutual relations of these materials. The relations of ores to slag, the value of fluxes, and the fluxing-requirements of each substance represented, stand out in graphic prominence. Often, however, it would be useful to extend the representation in some way, so as to obtain exact numerical values. One wishes to find how much ore and how much flux, thus represented, combine to produce the results desired. The present paper is written with the aim of providing for such cases. It presents a method of graphic calculation obtained by extending the work of representation. The example selected deals with the calculation of a blast-furnace slag; but this instance is taken as typical, rather than as pertinent to the needs of the smelter alone.

In the calculation of a blast-furnace charge, the metallurgist has a problem with many variables. Ores, flux, and all materials used on the charge, must be employed in proportions to satisfy many requirements, among which, a suitable composition of the slag is one of the most important. The slag-composition, however, and the greater number of other existing conditions, are seldom absolutely independent factors. Within certain limits, each condition is a variable, and depends upon others.

The adjustment of these variable conditions, to bring about results financially satisfactory, necessarily must be largely a

* *Zeitsch. Phys. Chem.*, 1893, vol. xii., p. 359.

† *Jour. Phys. Chem.*, 1896-7, vol. i., p. 403.

matter of judgment, and can be brought about only through an intimate knowledge of the many circumstances surrounding any case in question. The exact arrangement, however, giving the precise weight of each material used, is found from a slag-calculation; and such a calculation, determining the necessary proportions of ore and flux, is based upon a certain slag-composition, usually adopted for the immediate purpose, as an independent variable, but selected with due regard to many conditions, physical, chemical and economic—all of which are highly important.

The composition of the slag and of the ores that produce it is generally expressed in terms of only three constituents—*e.g.*, silica with two bases; the other substances which make up the varied composition being converted and eliminated in various ways to simplify the representative formula.

To control the composition of a slag with three variable constituents, a supply of three ore-materials is commonly necessary. More than three often have to be used; but in such cases they may be combined with one another in such a way as to reduce the number of materials requiring consideration. If the varieties of ore in the charge are numerous, they are "bedded" when this course is practicable, and thus a great variety of them is combined into what constitutes practically one material. If they are not actually bedded, but are regularly charged in uniform proportions, the calculation can be based upon an imaginary mixture. In any case, the simplified problem thus deals with three slag-materials, whether in ores or flux, each material composed of varying amounts of three slag-forming constituents, common to all; and the total weight of these constituents uniting to form a slag.

By employing the fourth co-ordinate in graphic work, it is possible to deal with materials of four constituents. Provided the four constituents constitute 100 per cent. of the slag-materials used, one can thus represent, for example, the properties of slags composed of silica combined with three recognized bases. Four ores or fluxes, each consisting of four constituents, common to all, but in varying amounts, would combine, in such a case, to form a slag, composed, it may be, of silica, alumina, lime and magnesia. In consideration of the more customary treatment of slags, however, in which only

two bases with silica are recognized, and on account of the disadvantages of calculating all materials upon a basis of 100 per cent., and, moreover, on account of the somewhat increased complexity in dealing with the slag and four ores rather than three, it has appeared inadvisable to discuss in this paper the use of the fourth co-ordinate in that precise connection.

In the present discussion, the fourth co-ordinate is utilized for another purpose, involving, perhaps, a greater need of its application,—namely, to represent the non-essential and non-slag-forming constituents of the ores and fluxes, and to treat them unitedly as a fourth variable. For example, the carbonic acid of the carbonates volatilizes and plays no part in the slag, yet this must be weighed with the ore, and is a part of the charge. Moisture and excess of oxygen likewise may be enumerated. Some of the metals and metalloids volatilize wholly or in part, leaving a deficit. One base, calculated in some molecular ratio with another, causes a further discrepancy. Deducting the metal-forming constituents of the ore, again, leaves a deficit. All these differences are here grouped into a fourth constituent, and are treated as a whole. The fourth constituent thus represents the difference between the part of a material which enters the slag and the whole (or 100 per cent.) of the material charged.

A calculation is described first without the employment of the fourth variable. This leads, in a way, to a more usual application in which the fourth variable is employed. For simplicity, some descriptions and relations common to both instances can be better illustrated in the first instance, and these are not repeated, therefore, in the second.

Calculation with Three Co-ordinates.

Suppose one has the three following materials, and with them desires to produce a certain slag. Let a thousand pounds be the required weight of the charge, and let the composition of the slag be selected as tabulated in the fourth column below.

	Siliceous Ore. Per cent.	Ferruginous Ore. Per cent.	Limestone. Per cent.	Slag desired. Per cent.
SiO_2,	60	30	25	40
CaO,	20	10	50	20
FeO,	20	60	25	40
Total,	100	100	100	100

Performing the work by an algebraic method, the necessary amounts of ores and limestone are found to be as follows:

	Lbs.
Siliceous Ore,	360
Ferruginous Ore,	480
Limestone,	160
Total,	1000

To calculate a slag thus, by the graphic method, one may use the tri-linear co-ordinate diagram paper, employed by Prof. Bancroft and others for various purposes, a good quality of which is supplied by the trade.* In Fig. 1, the line OX is taken as the zero-line for percentages of silica. Any point moving from the line OX toward the point Y increases in its represented silica constituent until the point Y is reached, when the per cent. of silica becomes 100. The line OY is the zero-line for the per cent. of lime, which per cent. is understood to increase proportionally for any point moving toward the point X. The line YX is the zero-line for ferrous oxide. The point O represents a substance composed of 100 per cent. FeO.

In dealing with substances composed wholly of silica, lime and the protoxide of iron, one understands the point f (Fig. 1) to represent a material composed of 30 per cent. SiO_2, 10 per cent. CaO and 60 per cent. FeO, these values being shown by the perpendicular distances between the point and the lines OX, OY and YX.

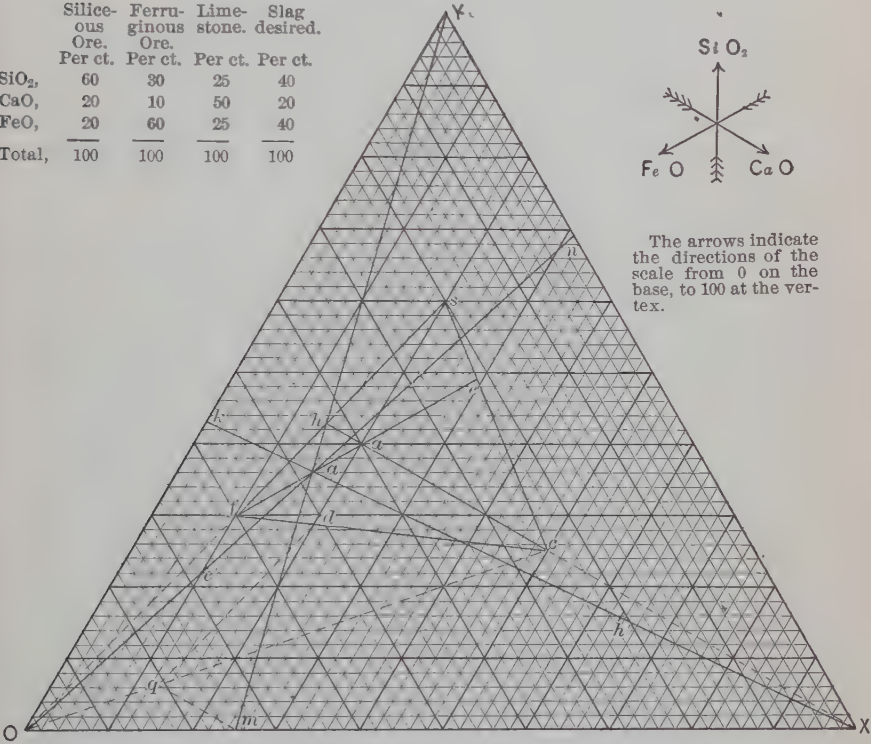
Thus, at the outset in the calculation, one marks on the diagram, by means of a needle-point, the points representing the three combining materials at hand, and also that of the desired slag. One thus has a graphic representation of the problem to be solved. The point f indicates the iron-ore; s, the siliceous ore, and c, the limestone. Within the triangle defined by the points f, s and c, lies the point a, the desired slag; and it is seen that this point must lie within such a triangle, if it be one that can be produced from a mixture of such materials as are represented. One notices also that the point a lies nearer the point s, or the point f, than it does the point c. The composition of the slag, consequently, more closely resembles that of the iron-

* Stationers can procure this paper, with printed diagrams $6\frac{1}{2}$ in. in height, from the Publishers of the *Journal of Physical Chemistry*, Ithaca, N. Y.

ore or of the siliceous ore than it does that of the limestone. It shows, therefore, that less limestone than of either ore will be needed in the charge. One may consider such a relation in the light that the influence of the limestone upon the slag is greater than is that of either ore, and therefore that less limestone will be required to influence or vary the composition of the slag to a given extent.

Fig. 1

	Siliceous Ore. Per ct.	Ferruginous Ore. Per ct.	Limestone. Per ct.	Slag desired. Per ct.
SiO_2,	60	30	25	40
CaO,	20	10	50	20
FeO,	20	60	25	40
Total,	100	100	100	100



The arrows indicate the directions of the scale from 0 on the base, to 100 at the vertex.

Diagram Representing the Calculation of a Slag from Materials Composed Entirely of Slag-forming Constituents.

To find the weights of the three given materials, *f*, *c* and *s*, required to produce the resultant slag, *a*, it is necessary first to observe the influence of each of these materials upon the slag. At the start, suppose the point *a*, representing the slag, to be a movable point, coinciding, in the beginning, with the point *f*. No amount of material *f*, added to such a slag, could in any way change its composition. The influence, when the points coincide, is therefore zero. Let now the moving point pass away

from the point *f* along the line *fc* and rest at the point *d*. There are now two materials represented which can enter into the composition of such a slag, namely, the materials *f* and *c*. While *f* is capable of influencing the composition in such a way as to draw the point in its direction along the line *fc*, the point *c* is capable of producing the opposite effect. No other point represented can fail to influence the point *a* out of the line *fc*, and therefore only materials *f* and *c* will be used.

These influences vary directly as the distance, since differences in composition are directly proportional to differences in distance. The weights necessary to produce these differences in composition, therefore, will vary *inversely* as the distance, and so when materials *f* and *c* combine to form a slag, at *d*, the relative amounts of materials *f* and *c* are represented respectively by the distances *cd* and *df*.

Now draw the straight lines *fa*, *ca* and *sa*, and extend them until they intersect the opposite sides of the triangle as at the points *d*, *e* and *h*. If the point *a*, representing the desired slag, which temporarily has been assumed to coincide with the point *d*, now move away from the line *fc* in the direction of the point *s*, a third material becomes a necessary addition to the mixture. As it was found to be the case on the base *fc* of the triangle *fcs*, so it is found to be the case on the line *ds* within the triangle *fcs*; the point *a*, moving along the line *ds*, would represent a material requiring in its formation amounts of *d* and *s* varying inversely as the distance. Thus the material *a*, as plotted upon the diagram, will be composed of a mixture of such materials as are indicated by the points *d* and *s*; and the relative amounts of *d* and *s* will vary as *a* moves along the line *ds*. The ratio of the amounts of materials *f* and *c*, however, which, combined, produce the material *d*, will not vary as long as *d* remains a fixed point; and since, by construction, the point *d* is an intersection of the extended straight line *sa*, *the ratio of distance df to distance dc*, which shows the relative amounts required of materials *c* and *f*, *is a constant*, while the point *a* is any point upon the line *ds*.

Not only is this relation true of distances between the points *f* and *c*, but it holds true of distances on the other sides of the triangle *fcs*, and it is true whenever straight lines are drawn through any point *a*, representing a possible slag, from the

vertices of the triangle, to the sides opposite, marking thus points of intersection upon those sides. The proportionate distances, moreover, can be transferred to any other triangle, and the same relation represented there holds true again.

In order to obtain these values from a uniform scale, let these distances be transferred proportionally to an equilateral triangle, in fact, to the main triangle OXY of the diagram. In so doing make the ratio of distances $Om : mX$ proportional to distances $fd : dc$; likewise make $Xn : nY$ proportional to $ce : es$, and also $Ok : kY : : fh : hs$. Lines drawn from Y to m and from X to k and from O to n intersect at a point a', since in transferring these proportional distances the point a has been moved proportionally and has become the point a'.

To transfer these proportional distances, there are simple ways. Geometrically it can be done as follows: Draw the straight lines fO and cX connecting the corresponding vertices of the two triangles fcs and OXY. A quadrilateral $OfcX$ is thus formed. Draw a straight line through d, parallel with the outer side, Of, of the triangle Ofc, and it intersects the inner side of the triangle at q. Then $fd : dc : : Oq : qc$. Now draw the line qm from the point q parallel with the outer side cX of the triangle OcX. Then $Oq : qc : : Om : mX$. The point m, thus located, corresponds to the point d.

A more rapid and still accurate way to locate the point m is to lay the straight edge of a piece of good paper along the line fc and to mark the points f, d and c with a sharp pencil on the straight edge of the paper. The marked edge may then be brought parallel with the line OX, by observing the horizontal division-lines of the diagram, and moved upward, keeping the edge horizontal, until the point made at f falls upon the line OY, and the point made at c falls upon the line YX. The point corresponding to d upon the paper edge is then pricked into the paper of the diagram with the needle-point and a line drawn from Y, through this point, strikes the line OX at m. The points k and n on the sides of the diagram triangle are located in this way, and, the lines kX, mY and nO being drawn, *a common point of intersection is found at a'.*

The triangle OXY now can be regarded as an enlarged projection of the triangle fcs upon some other plane. The material a' can be understood to be composed of materials repre-

sented by the points Y and m, and the material m be composed of O and X. Since the necessary amounts of materials are inversely proportional to their distances, the amount of material Y entering the mixture, if Y and m only were considered, would be shown by the distance $a'm$, while the combined amounts of O and X producing m and uniting with Y to form a' would be shown by the distance $a'Y$. Thus if the distance Ym represent 100 per cent., or the whole mixture, distance $a'm$ shows the per cent. of material Y in the mixture. Likewise if Xk represent 100 per cent., $a'k$ represents the amount of material X in the mixture; and the same is true in respect to distances on the line On. The lines Ym, Xk and On are seen to be divided into an equal number of divisions by the scale of the triangle, and proportionate distances may be read by these divisions, either along the lines, or as perpendicular distances from the sides of the outer triangle. The points O, X and Y correspond to the points f, c and s; therefore one may read directly from the scale of the large triangle, by distances between the point a' and the sides of the triangle, the amounts of materials O, X and Y, and therefore of f, c and s which are required.

With the scale divided into one hundred divisions as in diagrams which may be purchased, each division becomes 10 lbs. if one compute a 1000-lb. charge, and in such a case one estimates the single pounds by tenths of the smallest divisions. In the accompanying diagram, in which the total distance is divided into tenths by the heavy lines and into fiftieths by the lighter ones, the smallest division represents 20 lbs., or one-fiftieth of a 1000-lb. charge.

The amounts of siliceous ore, iron-ore and limestone are thus read from the diagram by the distances between the point a' and the respective sides of the triangle, and these distances are found to accord with the result obtained by algebraic calculation.

Summary.

The calculation with three co-ordinates may be outlined as follows: Locate upon the diagram the points representing the three ore materials or mixtures of materials to be treated. Connect the points by straight lines, forming thus an inner triangle. Plot the desired slag, which will be represented by a point within the newly constructed inner triangle. Draw straight

lines from the vertices of the inner triangle, through the point representing the slag, and extend them until they intersect the opposite sides of the inner triangle. (One of the three lines possible, in the foregoing operation, may be omitted if desired.) Transfer the points of intersection, now found, to corresponding points upon the sides of the outer or diagram-triangle, using a paper edge and employing three construction lines as described. Observe the common point of intersection within the diagram-triangle, and read directly the weights of materials required.

Calculation with Four Co-ordinates.

The calculation of a slag like the foregoing one is restricted in its application to materials whose percentage-composition in slag-forming constituents gives a total of 100. Practically, in the materials used there is a fourth constituent which does not enter the slag. Need of the fourth co-ordinate arises at this point. A system of representing the fourth variable, however different in some respects from any which has been used hitherto, is better suited to the purpose of calculation.

The composition of the materials supplied, it is assumed, has been altered by deducting whatever metal-, matte- or speiss-forming constituents were present, and also by grouping with CaO or with FeO the equivalents of other bases which cannot be taken into account individually. The composition of the resulting materials, the composition of the desired slag and the chosen weight of the charge are then represented as follows:

	Mixed Siliceous Ore. Per cent.	Limestone. Per cent.	Iron-Ore. Per cent.	Slag desired. Per cent.
SiO_2,	40	5	10	40
CaO,	5	50	5	20
FeO,	25	5	70	40
CO_2, etc.,	30	40	15	0
Total,	100	100	100	100

The result of calculation by an algebraic method would show the necessary weights of materials to form such a slag to be:

	Pounds.
Siliceous Ore,	638.6
Limestone,	201.7
Iron-Ore,	159.7
Total,	1000.0

In Fig. 2, one may consider that the triangular diagram represents the base of such a triangular pyramid as has been suggested by Prof. Howe.* In this case, however, points are not shown in perspective within the pyramid, but are represented in vertical projection upon the base. The height of the pyramid, moreover, for symmetry, may be made such as to produce

Fig. 2

	Siliceous Ore. Per ct.	Iron-Ore. Per ct.	Lime-stone. Per ct.	Slag desired. Per ct.
SiO_2,	40	10	5	40
CaO,	5	5	50	20
FeO,	25	70	5	40
CO_2, etc.,	30	15	40	0
Total,	100	100	100	100

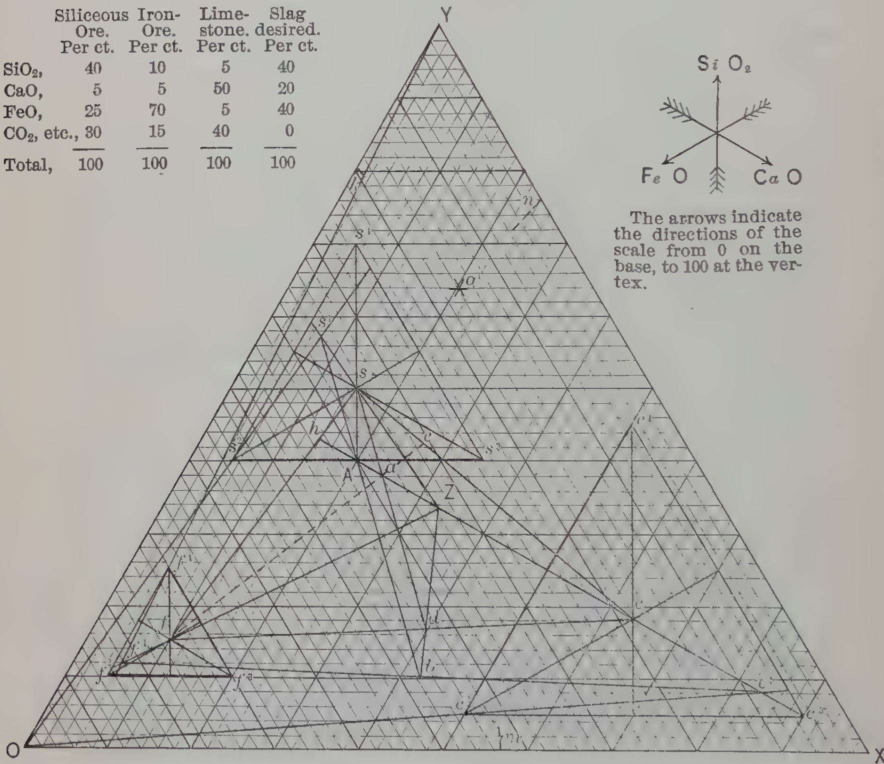


Diagram Representing the Calculation of a Slag Produced from Materials Composed Partly of Slag-forming Constituents.

a regular tetrahedron, with each face an equilateral triangle. The point Z is the upper vertex of the pyramid, and though represented at the center of the triangle OXY, it is understood to lie above the plane OXY a certain distance, to define, with the other points, the solid figure $ZOXY$.

All points of variable positions within the pyramid $ZOXY$

* *Trans.*, xxviii., 353.

necessarily recede from three of the faces as they approach any one face perpendicularly; and if the perpendicular distances between a point and all the faces were added, the sum would be a constant, wherever the point might be situated within the pyramid. These four perpendicular distances are the four possible co-ordinates of any point represented; and it is upon the direct or indirect use of these co-ordinates that the subsequent work depends.

Since all points are represented in vertical projection, it is clear that there is no direct measurement that will show the height of any given point above the plane OXY. Moreover, the distance between any point and the side planes OZX, XZY and YZO will vary when its distance from the basal plane OXY is made to vary. The system requires, therefore, some further means of measurement; and in that measurement all co-ordinates must be represented in actual distances upon the plane surface OXY.

Representation of Four Co-ordinates.—The material for representation, which contains four constituents and requires four co-ordinates, one represents in a certain way, upon the plane surface OXY by three of its co-ordinates. One neglects the fourth and proceeds to represent the three in the manner employed in the preceding problem where only three constituents were present. The three co-ordinates in this case fail to meet at a single point on account of the diminution of their values to make up the fourth co-ordinate, which has been neglected. If, however, one lay off these distances toward the interior as far as they are capable of extending, and indicate the termination of such distances by lines parallel with the sides of the triangle from which such distances are measured, one thereby constructs an inner triangle similar to the outer one, which in a certain way represents the material in place of a single point.

The distances between any side of such an inner triangle and the corresponding side of the outer, or diagram-triangle, shows the corresponding constituent of the material represented; since, in the construction, these distances were based upon those values. Moreover, the distance across such an inner triangle shows the magnitude of the fourth constituent, because the altitude of an equilateral triangle, being equal to the combined length of any three perpendiculars to its sides which meet in a point,

this altitude shows the total diminution of the first three constituents occasioned by the existence of the fourth.

A substance designated by four co-ordinates upon the plane of the paper, therefore, will form a triangle contained within the triangle OXY and similar to it. *The distances between the sides of the inner triangle and those of the outer one represent the values of three of the four possible co-ordinates, while the altitude of the inner triangle represents the value of the fourth co-ordinate.*

These distances upon the base are *proportional* to the co-ordinates of some single point within the pyramid $ZOXY$, but above the plane OXY. The point whose co-ordinates are so represented, as can be demonstrated readily, would form the upper vertex of a certain interior pyramid, constructed upon this inner triangle as a base. The inner pyramid would be similar to the outer one, and all its faces would be parallel with those of the outer one, while its base would consist of the triangle which we have been considering, and the plane of its base would coincide with the plane of the base OXY.

Taking the triangle $s_2s_3s_4$ for illustration, it may be considered that the point s, shown at the center of the triangle, represents the upper vertex of an interior pyramid ($ss_2s_3s_4$). Such a point with its encompassing triangle indicates a material of a definite composition. The distance between the point s and the plane OZX, for example, corresponds to the distance between the line s_2s_3 and the line OX; distance between the point s and plane OZY corresponds to distance between the line s_2s_4 and line OY; distance between s and plane YZX corresponds to distance between lines s_3s_4 and YX, while the distance between the point s and the base OXY corresponds to the distance between any side line of the triangle $s_2s_3s_4$ and the opposite vertex; for instance, distance between line s_2s_3 and point s_4. These distances upon the base OXY are actually projections in three different directions of distances within the pyramid. All that one need consider, however, is that such distances on the base correspond to the actual co-ordinates of a point within the outer pyramid, and that this point is the upper vertex of an interior pyramid represented by this equilateral triangle and the point at its center.

The first step in calculation, knowing the chemical composition of the combining substances, is to indicate the siliceous ore,

the iron-ore, limestone and slag by the points s, f, c and A respectively. Upon the plane surface OXY one calls distance from the line OX toward Y, per cent. silica; distance from the line YX toward point O, per cent. iron oxide; and distance from the line OY toward point X, per cent. calcium oxide, as before. One now, dealing with four co-ordinates, understands that these distances on the base correspond to perpendicular distances from the planes OZX, YZX and OZY into the interior of the pyramid and toward the opposite vertex.

To represent the siliceous ore of the accompanying table, for example, one may draw upon the diagram along the line indicating 40 per cent. SiO_2, the line s_2s_3; along the line indicating 25 per cent. FeO, the line s_3s_4; and along the line indicating 5 per cent. CaO, the line s_4s_2. The fourth, or volatile, constituent is shown by the size of the triangle $s_2s_3s_4$, and can be read by the number of included printed divisions between one of its sides and the opposite vertex.

The central point of this triangle is found by drawing perpendiculars to its sides passing through its vertices, or by bisecting its sides and connecting the points of bisection with opposite vertices. The point of intersection between two such lines indicates the center, while the third line may be used to confirm the accuracy of the measurement, if desired. The point of intersection s, thus located upon the diagram, represents the upper vertex of the pyramid $ss_2s_3s_4$. The points f and c likewise indicate such upper vertices of similar pyramids representing iron-ore and limestone in the same manner.

The slag contains no fourth constituent, and is therefore represented by a single point, A, upon the plane OXY. If there were a fourth constituent in the material, the point would be replaced by a triangle of size determined by the value of the fourth constituent, and would be treated accordingly.

Projections from the Upper Vertex.—There is a point upon the base of each of these interior pyramids, found by noting the point of intersection of any two straight lines drawn through any two corresponding vertices of the exterior and interior pyramids, which represents the material with its fourth constituent eliminated. Such a point is s', for example. This point is to be regarded as the projection from the vertex Z, of the point

s, upon the base OXY. Three constituents represented by the point remain in unchanged proportion, while the fourth has disappeared. The three co-ordinates merely have increased in value to correspond to the decrease of the fourth co-ordinate, thus keeping the sum a constant.

To see more clearly the relations between interior and exterior pyramids, and to understand better the significance of the point s', one may observe what changes occur when the vertical or fourth co-ordinate of a represented substance is made to vary.

Taking the case of the pyramid $ss_2s_3s_4$, let the point s rise vertically from the plane OXY. The vertical projection of the point s remains fixed, and at the center of the triangle $s_2s_3s_4$. The triangle $s_2s_3s_4$, however, increases in size by this change, until one of its sides coincides with one of the sides of the outer triangle. At this point the increase must stop, for the point s has reached one of the faces of the outer pyramid, and the value of that corresponding co-ordinate has become zero. This change, brought about by the increase of the fourth co-ordinate, has diminished the first three co-ordinates, but it has not diminished them proportionally. Each distance has received the same diminution, but the diminution has not been proportional to the original distance. The composition of the slag-forming component has changed.

If the vertical co-ordinate of the point s now be made to increase *without changing the proportions of the first three co-ordinates*, the point will move not perpendicularly from the plane OXY, but in a straight line toward the upper vertex Z, the point at which all three values become zero. All changes in value of the fourth co-ordinate produce corresponding movement of the point s on the line sZ or its extension, in case the proportions of silica, lime and iron remain constant.

During this change, moreover, as the pyramid increases or decreases in size, by variation of the vertical co-ordinate, the ratios of silica, lime and iron remaining constant, any vertex (s_2) must pass along a straight line toward the corresponding vertex (O) of the outer pyramid. Any point on this line is proportionally distant from the two faces OZX and OZY, or from the two lines OX and OY, the zero-planes, or the zero-lines, for silica- and iron-constituents. Any point on the base OXY,

but not on this line s_2O, would represent a different proportion of silica and iron; a condition contrary to supposition. Therefore the point s_2, throughout such a variation, will rest upon the same straight line Os_2, or its extension, and differences in value of the fourth co-ordinate will produce corresponding movement of the point s_2, on this line.

There are two limits to these changes in value of the fourth co-ordinate and the corresponding changes in the pyramid. One limit is reached when the fourth co-ordinate increases to the full height of the outer pyramid—the maximum limit. In this case all the sides of the triangle $s_2s_3s_4$ have diverged, and finally have coincided with the sides of the triangle OXY, and the point s has reached the point Z. There can be no further increase in the size of the interior pyramid; for it now coincides with the outer one, and the material represented by it consists of 100 per cent. fourth constituent and 0 per cent. of any other constituent. The other limit is reached when the fourth co-ordinate decreases to a value of zero. By this change, as the pyramid decreases in size, the points s_2, s_3 and s_4 approach a single point, and, as they do so, move only along the lines $s'O$, $s'Y$ and $s'X$ (the two latter not drawn in Fig. 2, but easily imagined). Similarly, the point s, receding from Z approaches the same single point, a pyramid indefinitely small, upon the base OXY. The intersection of any of these lines thus defines the point s'.

The points s', f' and c' are now located in the foregoing manner, drawing a straight line for each material, from an outer vertex through a corresponding inner one, and noting the point at which such a line intersects another, similarly drawn, through other corresponding vertices. As the lines Zs', Zf' and Zc' will be of still further use, let these lines be three used to define the points s', c' and f'. The other necessary lines may be drawn through any corresponding vertices found convenient; for example, the straight lines Os', Oc' and Yf'.

If the representation of the slag consisted in a pyramid rather than a point, this corresponding projection would be found also for that substance. The projected point would correspond, then, to the point A, as represented upon the diagram, and would have the same significance as the point A now has.

In any case, one connects the points A and Z by a straight line, and remembers that any point upon this line represents a slag of uniform composition, as far as the slag-forming constituents alone are concerned; for the volatile fourth constituent does not enter the slag and is eliminated.

The points s, c and f now are connected by straight lines and a triangle fcs is formed. This triangle in most cases is a scalene-triangle, and its plane is inclined at some angle from the plane of OXY. It is always in such a position, however, that the line AZ intersects its plane at some point within its boundaries, if the slag be one that can be produced from the given mixture. This point of intersection now must be found; for this point, represented at a, upon this elevated plane, will show the actual slag that will be formed, and also will take into account the fourth variable.

If the points s, c, f and a all lie upon the same plane, the same relation between slag and combining materials exists as was the case in the preceding problem, where three variables were employed, when the triangle fcs rested upon the basal plane. Any distances marked off upon any given side of a triangle are proportional to corresponding projected distances, upon the side of a projection of that triangle, upon any other plane. The triangle fcs represented upon the plane surface of the diagram is the vertical projection of the inclined triangle upon a horizontal plane. One proceeds, therefore, to find the point a, and, having done so, to transfer the point to a corresponding position, a', on the triangle OXY, following the method described in the first problem, ignoring the fact that the triangle fcs is an inclined one. Only while locating the point a upon the triangle fcs, need one keep in mind that the plane fcs is not the plane of OXY.

The point a, upon the triangle fcs, may be located as follows: Connect the points f' and c' by a straight line. This line rests upon the base OXY. Draw the straight line $s'A$ through the point A and extend it to the point b. Since points s', A and the line $f'c'$ lie upon the plane OXY, the point of intersection, b, also is upon the basal plane. The points Z, f' and c' define a triangular plane, upon whose edges rest the points b, f and c. Connect points f and c by a straight line and then draw the straight line Zb. The line Zb intersects the line fc upon the

inclined plane $Zf'c'$ and marks a point d, upon the edge of the plane fcs. $Zs'b$ is a triangular plane upon whose edges rest the points d, A and s. The points s and d lie upon both the planes fcs and $Zs'b$. Draw sd, marking thus the line of intersection between these planes. The line ZA rests upon the plane $Zs'b$; it therefore intersects the line sd; and, since the line sd rests also upon the plane fcs, the point of intersection, a, also rests upon the plane fcs.

The point a now located, one proceeds to find the corresponding point a' upon the triangle OXY, by transferring the distances set off by the points d, h and e to proportional distances on the sides of the triangle OXY. One then connects these new points with the vertices opposite, as in the first problem, and thus finds the point of intersection at a'.

The point a' thus located, shows by its distance from the lines OX, XY and YO the weights of siliceous ore, iron-ore and limestone which must be used to produce the required slag; and this result accords with the numerical one indicated. The procedure, perhaps long in description, is simple in practice and requires but a few moments actual work.

Summary.

The following order may be observed in performing the successive operations in calculation with four co-ordinates:

Plot upon the diagram the triangles representing the materials to be employed ($s_2s_3s_4$, $f_2f_3f_4$, $c_2c_3c_4$), and the point representing the slag, or desired mixture, (A). Find the centers of these triangles, (s, f, c). Connect these centers by straight lines, (sf, fc, cs). Find the center of the diagram-triangle, (Z). Draw straight lines from the center of the diagram-triangle, through the centers of the inner triangles, extending the lines beyond, generally to the farther side of the inner triangles, (Zs', Zf', Zc'). Draw straight lines through some vertex of each inner triangle from the corresponding vertex of the diagram-triangle, extending these lines into the interior of the inner triangles, (Os', Oc', Yf'). Note the point at which these lines intersect those drawn in the preceding operation, (s', f', c'). Connect any two of these newly found points of intersection by a straight line, (f' c'). The third corresponding point of intersection connect with this line by another

straight line, passing through the point representing the slag, (s' b). Note the point at which these lines intersect, (b). Connect this point with the center of the diagram-triangle by a straight line, (bZ). Note the point at which this line cuts a side of the scalene-triangle, (d). Draw a straight line from this point to the opposite vertex of the scalene-triangle, (ds). Draw a straight line connecting the center of the diagram-triangle with the point representing the slag, (ZA). Note the point at which this line intersects the line drawn in the preceding operation, (a). Draw lines through this point from the vertices of the scalene-triangle to the opposite sides, (sd, ch, fe). Note the points of intersection thus made upon the sides, (d, h, e). Transfer these points to corresponding ones on the sides of the diagram-triangle in the way described (m, n, k). Connect these newly found points with the opposite vertices by straight lines, (On, Ym, Xk). Observe the common point of intersection, (a'). Read directly the weights of materials required.

ADAPTATIONS.

These methods can be subjected to certain simple adaptations which render their use possible in some broader applications. According to the object of calculation, whether it be that of calculating a slag, or of producing a mixture for any purpose, special needs may arise. A few instances are cited in the succeeding paragraphs illustrating the possibility of adapting the method to needs more varied than can be considered here in detail.

Reversing the Calculation.—If occasion require, for example, one may decide upon the location of the point a' definitely at the outset. It is not difficult in such a case to extend the calculation backward, in exactly a reverse manner, finding where the point A, the slag, will lie if the point a', the proportions of ore to flux, be modified to suit other conditions.

Other Triangular Diagrams.—Triangles of other forms than the equilateral ones here employed could be used in any of the foregoing work, provided the subdivisions were equidistant upon any given side and were equal in number upon all sides. The point Z, as the upper vertex of the solid figure, may be made any point above the plane of the base, so long as the inner triangles and interior pyramids are made similar to the outer

and exterior ones. A right-angled triangle with the point Z situated vertically above the vertex of the right angle, or preferably an equilateral triangle with the point Z vertically above some one of the vertices, are forms that possess some advantages in construction. In such cases the upper vertex of the tetrahedron and the vertex of the angle below it are represented by the same point, and the need of finding the vertical projection of the vertex of any interior tetrahedron is obviated. Projections from the upper vertex, Z, to the triangular base, in any such case, can be found in a strictly analogous manner; but the lack of symmetry and some other disadvantages make these departures generally less satisfactory for varied work.

Representation by Single Lines.—It frequently is found convenient to represent substances of four constituents by single lines upon the diagram. This occurs sometimes when many materials are represented upon one diagram for purposes of comparison. Such simpler forms facilitate the work also, when transferring represented materials or parts of calculations from one diagram to another. It will be seen that a line connecting the upper vertex of an interior pyramid with the projection of that vertex upon the base, from the point Z, can be made a substitute for the pyramid for most purposes. Such a line is $s's$, for example. The point s' at the outer end of this line, on the plane OXY, shows the composition of a component consisting of the first three constituents. The magnitude of the fourth constituent is shown by the length of the line, when this length is compared with the whole distance between the point s' and the point Z. The line in reality lies above the plane OXY and has a certain inclination from that plane, but differences in distance upon the line are proportional as seen in vertical projection upon the paper. Such lines transferred from one diagram to another are $s's$, $f'f$ and $c'c$, shown in Figs. 2 and 3. When understood, the lines signify definite compounds of four constituents, and calculations may be based upon them.

Combining Two Materials.—If for some special reason a fourth material were to be considered in the diagram, and were to replace some part of one of the first three materials, it could be combined with such material in a manner shown in Fig. 3. Upon such a diagram, the triangle representing the fourth material is first constructed; the center of the triangle, representing the

vertex of a pyramid, is found; the projection of that vertex from point Z to the base is then located; the central point, or vertex, and its projected point are connected by a straight line; the length and position of the line are seen, $(g'g)$. In this case a straight line connecting the points g and s, and one connecting the points g' and s', will both be intersected by any straight line drawn from Z to intersect $g'\ s'$. In this way the line $r'r$, pro-

Fig. 3

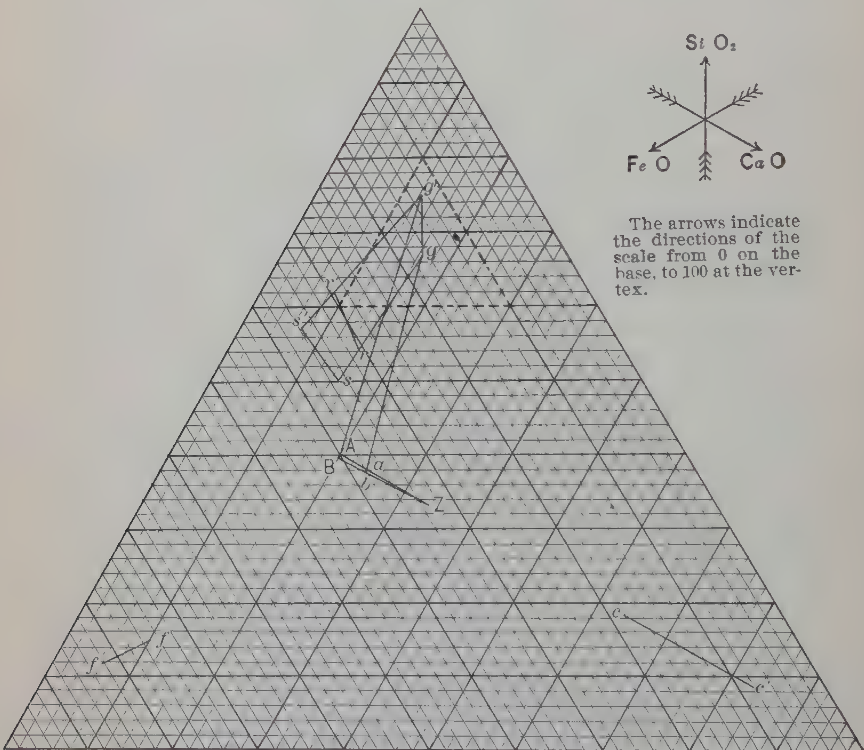


Diagram Showing Methods of Combining Slag Materials.

duced, represents the composition of a mixture of the two materials. If one desire three parts, for example, of material s to one part of the fourth material, then one divides the line sg into four parts, and lets the distance of the new point r from the points s and g be inversely proportional to the amounts of g and s. Then the point r will lie one division from s and three divisions from g. Drawing Zr' through r, the line $r'r$ defines the mixture. Such an indicated mixture can be transferred

to a new diagram if desired, or calculated directly with $f'f$ and $c'c$ as though a single material.

Consideration of Fuel-Ash.—In another instance it may be desired to add a fourth material in some definite proportion to the whole mixture. For example, suppose the substance $g'g$ to be a coke-ash, entering the slag to the extent of 1 per cent. coke-ash for every 100 per cent. of the charge. The point a can be found first, as in Fig. 2. This done, the line ag shows the line of influence between the points a and g. In order to counteract the influence of the material g upon the slag a, it will be necessary to produce from the ores a slag which influences the point a from the opposite direction. In this case the line ga is extended beyond the point a, a distance of one one-hundredth part of its original length to a new point b, as shown in the figure. A line drawn from Z, through this point b, intersects the extension of the line $g'A$ at the point B; and the point B, thus indicated, shows the necessary composition of the slag from the ores, to combine with the coke-ash and produce the slag A. The total weight of the mixture will be increased ten pounds by the weight of the ash, and this increase would make a charge of 1010 lbs. if the fourth material were weighed with ore and flux. Weighed as fuel, the charge remains 1000 lbs., while the influence of the ash is properly counteracted in the slag.

Conclusion.—In the general consideration of the method of graphic calculation, the question concerning rapidity and accuracy naturally arises. These factors will be found partly individual ones in practice, depending upon skill and care. Compared with the performance of an equal amount of work with an equal degree of accuracy, by algebraic methods, an important saving of time is effected, while close application to numerals is avoided. A degree of accuracy within one-tenth of one per cent. in the final result is commonly obtained with diagrams $6\frac{1}{2}$ in. in size. A hard pencil sharpened to a chisel-point and a perfect straight-edge must be used for drawing the necessary construction-lines, however, and a needle-point is used for marking the points of intersection. With these simple appliances, and with a supply of tri-linear, co-ordinate, ruled paper, results satisfactory for many purposes can be obtained.

The Great Oil-Well Near Beaumont, Texas.

BY ANTHONY F. LUCAS, BEAUMONT, TEXAS.

(Richmond Meeting, February, 1901.)

I. The History of the Well.

Certain geological indications at Glady's station, four miles south of Beaumont, on the Sabine and East Texas railway (a branch of the Southern Pacific) induced me to undertake a thorough test of that locality by means of a well. I had been making reconnoissances for nearly two years in that part of Texas, before deciding upon this supreme effort.

Three previous attempts had been made in the same place: one in 1894 by Messrs. Sharp & Co.; one in 1896 by Mr. J. Looney; and one in 1898 by Messrs. Savage Bros. They had all failed to pass though the immense thickness (500 ft.) of quicksand which underlies the surface soil, clay, etc. At first, I employed the system of boring which I had previously used in the Louisiana salt-deposits.* But I soon found that this method was inadequate, without modification, to deal with the quicksand. Accordingly, I adopted the use of large and heavy castings, and pipes of 12, 10, 8, 6 and 4 in. diameter, successively telescoped one into the other. Boring was begun by Messrs. Hamill Bros., of Corsicana, contractors, about the middle of October, 1900; and on January 10, 1901, after many difficulties, a layer of rock containing marine shells was reached, at the depth of 1160 ft. For 150 ft. immediately above, the drill had passed through layers of sandstone and concretions of limestone. At this time there was about 600 ft. of 4-in. pipe, weighing at least 6 tons, in the well; and this, together with the next (6-in.) casing above, was filled with water. When the rock was penetrated the well "blew out," lifting the whole of the 4-in. pipe. Mr. Hamill was on the top of the 60-ft. derrick when

---

* See my paper on "Rock-Salt in Louisiana," *Trans.*, xxix., 462, in which (p. 467) this system is described.

the pipe began to move; but the beginning was so gradual that, warned by the outflow of the water, he had ample time to climb down and retire to a safe distance before the pipe was shot into the air. It went to a height of 300 ft. above the derrick, the upper works and heavy tackle of which it carried away; then, twisted and bent by the strong wind which was blowing at the time, it broke off with a crash and fell to the ground, fortunately injuring no one. The remaining 4-in. pipe, freed from the weight of the upper portion, followed with greater rapidity, and was shot through the top of the derrick. Simultaneously, the water which filled the well (being used to keep the pipe-lining clear by removing upward the *débris* of drilling) was expelled to a great height; and a column of gas, rock-fragments and oil followed it, at first at the rate of about 250 barrels per hour, rapidly increased to 500, 1000 barrels, etc., until on the third day the discharge (by that time carrying no solid matter and a diminished quantity of gas) was estimated by officials and engineers of the Standard Oil Co., who were naturally the most experienced judges, to be at least 3000 42-gallon barrels of oil per hour, or about 75,000 barrels in 24 hours. Probably I had been too conservative in my previous estimates. Fig. 1 is from a photograph taken at this period.

II. The Control of the Well.

Since this unprecedented outbreak took us by surprise, it was necessary to improvise some means of preventing the total waste of the oil ejected, and at the same time to devise a method for getting the stream under control. To attain the first object, we hastily constructed dams or levees to surround the oil. The first one, about 2.5 ft. high, was overflowed in 24 hours; a second and a third, embracing larger and larger areas, the latter covering about 50 acres, were likewise overflowed. The clay soil seemed to hold the oil fairly well, but the constant danger of fire was a source of great anxiety, by reason not only of the direct loss of oil, but also of the incidental damage which it might occasion; and, above all, because the ignition of the spouting column itself would make it difficult or impossible to recover and control the well. Even more important, therefore, than the immediate saving of the oil was the shutting of the well. Operations for both purposes were carried on simultaneously.

I was flooded with telegrams, letters and personal applications by the hundred from parties proposing to undertake the closing of the well—for large rewards. Some of them required cash down (ranging from $30,000 to $100,000); some would not divulge their proposed methods until paid; others submitted their plans; most of them were cranks, but a few had very sensible ideas. I decided to give the first opportunity to my contractors, Messrs. Hamill Bros., subject to my approval of their plan, which I gave, after suggesting certain modifications.

The apparatus used consisted of a carriage, anchoring an 8-in. gate-valve against upward movement; below the valve a short nipple, with an 8-in. tee attached. The whole apparatus was to be launched against the column of solid oil. This constituted the critical part of the operation. But, since the oil was spouting through a 6-in. pipe, and my main outside casing was 8 in. in diameter, the new 8-in. valve, if successfully placed over and connected with the 8-in. well-casing, would permit the stream to go on flowing, with an enlarged diameter (or, in other words, with one-inch "play" all round it), so that the flow would not be checked by this part of the operation. The result answered our hopes. Notwithstanding the violent impact of the oil-column, the carriage was successfully placed over the well, and the valve, etc., were drawn down with the aid of bolts until the tee could be screwed into the 8-in. casing.

When this had been accomplished the oil was freely flowing through the open 8-in. gate-valve. We then inserted into the tee outlet a piece of 6-in. horizontal pipe, with a 6-in. gate at the end; and after bracing the 8-in. valve as firmly as possible, we gradually closed it, diverting the stream into a horizontal direction, and carrying it out of our way. This gave us opportunity to dig around the well, beneath the derrick, and place foundations for an anchorage, which would effectively hold down not only the valves, etc., but also the casings.

After this we packed oakum tightly between the 8-in. and the 6-in. casing; placed a heavy wrought-iron clamp around the former, and by means of strong set-screws secured the 6-in. pipe against any possible upward movement. Finally, by closing the 6-in. gate-valve on the horizontal pipe, the flow of oil was entirely cut off. This was done January 19th, at 11.10

A.M., nearly nine days after the well began to flow. The pressure after shutting-down, as determined by a gauge connected

Fig. 1.

The Lucas Oil-Well at Beaumont, Texas.

with the tee, was 104 lbs. per sq. in.—considerably less than had been inferred from the violence of the stream.

Fig. 2 shows the apparatus as fitted to the well at the moment of the shut-down.

For further protection against fire, a large iron cylinder was constructed to contain the valves, tee, etc., above ground, with a surrounding packing of sand, so that a conflagration in the oil-pools may not be communicated to the well.*

There was naturally some doubt whether the well would respond promptly when reopened after a period of complete closure. To test this point, the well was reopened about six weeks after the operation above described. Some gas was discharged at first; but the solid stream of oil was immediately restored.

III. The Oil-Rock.

The fragments of the rock, thrown violently out through the iron-casing from the depth of 1160 ft., were naturally much broken and abraded. Only one piece was two or three inches in diameter; the rest were much smaller. A handful of the latter, together with the larger one referred to, were submitted to Prof. Gilbert Van Ingen, of Columbia University, New York, who kindly consented to examine the rock and the shells therein contained. He reports that the rock is a compact quartz sandstone, with grains of pellucid quartz, varying from round to crystalline. The fossils are in layers, the oyster-shells having been apparently washed into their present position by wave-action. The interspaces between the oyster-shells are occupied by less compact sand, full of small lamellibranch shells. These are seldom perfect; and, on the whole, the material is so fragmentary that identification of the species is very difficult or impossible. They are clearly Tertiary, but whether Eocene or Miocene, does not clearly appear. The following list comprises all that Prof. Van Ingen could make out: *Ostraea* (sp.?), very abundant; *Turritella* (sp.?), in a fragment; *Mactra?* (sp.?), very small, and not positively identified. In addition to these, there was found a fragment of lignitized wood.

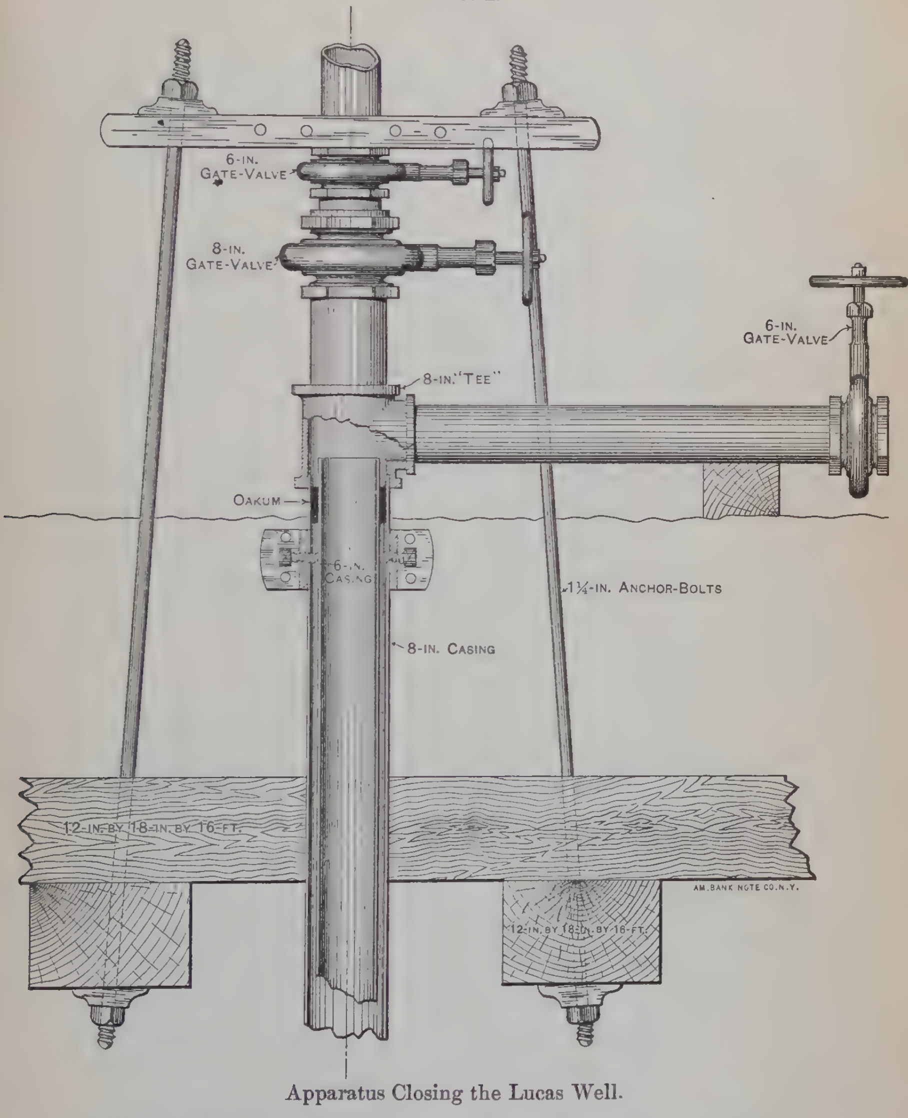
IV. The Oil.

Dr. A. R. Ledoux, of New York City, kindly caused a sample of this oil to be tested in his laboratory. His report follows:

* Note by the Secretary.—The wisdom of these precautions is shown by the occurrence of such a conflagration, early in March, to which reference is made in a postscript to this paper.—R. W. R.

"I received a sample of the Beaumont, Texas, petroleum from Dr. R. W. Raymond on January 22, 1901, and had it ex-

Fig. 2.



Apparatus Closing the Lucas Well.

amined in my laboratory,—the work being performed by Mr. A. M. Smoot, our chief chemist. The results are as follows:

"The specific gravity of the crude oil at 60° F. (15.5° C.) is 0.925, equivalent to 21.5° Beaumé.

"Distilled, after the process described by Boverton Redwood in 'Petroleum and its Products,' with apparatus strictly in accordance with Engler's specifications as given in that work, the sample yields:

"Distillation begins at 150° C.

	Percentage by Volume.	Sp. Gr. of the Fraction.
150° to 200° C. (302° C. to 392° F.),	6.0	0.851
200° to 250° C. (392° C. to 482° F.),	13.5	0.867
250° to 300° C. (482° C. to 572° F.),	28.0	0.886
300° to 400° C. (572° C. to 662° F.),	50.0	0.914
Residue and loss,	2.5	

"The crude oil contains 2.04 per cent. of sulphur (determined by Carius method).

"The specific gravity of some well-known crude petroleum oils is as follows: Pennsylvania, 0.801 to 0.817; Russia (Baku), 0.859 to 0.871; Alsace, 0.907; Lima, O., 0.816 to 0.860.

"It will be seen that the specific gravity of the Beaumont oil is far higher than that of oils which yield notable quantities of illuminants. The gravity of some Wyoming oils, however, equals and even exceeds that of the Beaumont oil. Kansas petroleum is quoted by Redwood as showing a gravity of 0.927; and that of one sample of Pico Cañon (California) oil is given by the same authority as 0.927.

"The Beaumont oil is very high in sulphur. Lima oil, the best known of the sulphury oils, is stated by Maybery and Smith to contain 0.55 per cent. of sulphur. Redwood gives the sulphur in a sample of Canadian oil as 0.98 per cent. The oils of Alsace are said by the same authority to contain from 0.134 to 0.138 per cent., and those of Peine (Hanover) from 0.077 to 0.085 per cent.

"Some of the California oils are very high in sulphur; but no reliable figures as to the actual percentage are at hand.

"Consideration of the distillation-figures obtained from the Beaumont oil shows at once that the sample is not at all comparable with Ohio or Pennsylvania oils as to the yield of illuminating oil.

"The following table taken from Sadtler's *Industrial Organic Chemistry* gives the fractions obtained from several well-known oils. The figures are due to Engler, and are therefore comparable with the figures obtained on the Beaumont oil, which was distilled in accordance with Engler's specifications.

Crude Oil.	S. G. at 17° C. (62.6° F.)	Began to Boil.	Came Over Under 150° C. (302° F.)	Between 150° and 300° C. (302° and 572° F.)	Above 300° C. (572° F.)
		°C. °F.	Per cent.	Per cent.	Per cent.
Pennsylvania 1	0.8175	82 = 179.6	21	38.25	40.75
" 2	0.8010	74 = 165.2	31.5	35.00	33.50
(Galicia Sloboda)	0.8235	90 = 194.	26.5	47.00	26.50
Baku (Bibieybat)	0.8590	91 = 195.8	23	38.00	39.00
" (Balakhani)	0.8710	105 = 221	8.5	39.50	52.00
Alsace (Pechelbronn)	0.9075	135 = 275	3	50.00	47.00
Hanover (Oelheim)	0.8990	170 = 338	......	32.00	68.00
Beaumont	0.925	150 = 302	......	41.50	50.00

"In examining the Pennsylvania and Ohio oils it is customary to regard the fraction distilling between 150° and 300° C. (302° and 572° F.) as burning-oil. Some of the heavier Russian oils yield illuminants only up to 285° C. (545° F.).

"The fractions obtained from the Beaumont oil between 150° C. and 300° C. are much heavier than the corresponding fractions from Pennsylvania oils; heavier even than the Russian.

"This is shown by comparison with the following table of the gravities of burning-oils, taken from Redwood (p. 203):

	Boiling point 150° to 300° C. (302° F. to 572° F.)
Kaiser oil,	0.780 to 0.800
American Illuminating oil,	0.800 to 0.810
Russian Illuminating oil,	0.820 to 0.825
Standard White oil,	0.808 to 0.812
Prime White oil,	0.800 to 0.806
Astraline,	0.850 to 0.860

"No considerable fraction of the Beaumont oil has a gravity less than 0.867,—the greater part of the portion distilling under 300° C. (572° F.) has an average gravity of 0.886. It, therefore, does not seem likely that the Beaumont oil will yield a desirable burning-oil by normal distillation.

"To determine whether or not the "cracking" process of distillation would yield burning fractions of lower gravity than those obtained by the normal distillation, a sample was treated in a distilling flask of large capacity in proportion to the amount of oil contained in it. The distillation was conducted so that the lighter vapors condensed in large quantities on the

cool sides and in the long neck of the flask, running back into the very hot residue. The distillation was conducted slowly, yielding: 1st drop at 92° C. (197.6° F.).

	Percentage by Volume.	Sp. G. of the Fraction.
92° C. to 150° C. (197.6° to 302° F.),	2.3	0.839
150° C. to 200° C. (302° to 392° F.),	1.9	0.852
200° C. to 250° C. (392° to 482° F.),	21.9	0.875
250° C. to 300° C. (482° to 572° F.),	31.1	0.899
Over 300° C. (572° F.),	34.2	0.905

"The yield of distillate at temperature under 300° C. (572° F.) is increased by the cracking, but the specific gravity of the fractions is also increased.

"The conclusions to be drawn from this investigation, as far as it goes, are that the Beaumont oil is very high in sulphur; that it will yield less than 10 per cent. of kerosene,—probably nearer 5 per cent., and only limited quantities of a very heavy burning-oil, similar in specific gravity to Russian Solar oil. The chief application of the Beaumont oil will no doubt be for fuel-purposes.

"Of course a new product like this has been examined by others, and I have been favored with some of the figures obtained. One sample showed:

Specific Gravity,	25.40° B.
Flashed,	In Open Cup at 165° F. (74° C.)
Cold Test,	Not congealed at minus 10° F. (23.3° C.)
Viscosity,	At 70° F. (21° C.), 98.

"In ten distillates of equal quantity the successive fraction varied in gravity from 38° B. to 22° B., the increase in gravity being fairly regular from 38 to 22; the pitch remaining in the still at a melting-point of about 300° F. (150° C.). It may be said that this oil seems to have an asphalt base, which simply means that its products do not belong to the Paraffine series.

"It is quite probable that a good many chemists have also analyzed this oil, but the only published test which I have seen appears in the Bradford *Daily Record* of January 31, 1901, and is as follows: (It will be noted that the results of Mr. Emery practically confirm our own.)

"'The Beaumont, Texas, oil is of a dark green color and has an offensive odor, similar to that of Lima and Canadian oils, with the odor of sulphuretted hydrogen more pronounced.

"'The crude oil has a flash test of 110 (43.3° C.) degrees Fahrenheit, and fire test of 180 (82.2° C.) degrees; gravity at 60 (15.5° C.) degrees Fahrenheit is 23.6 degrees Beaumé.

"'The oil showed no evidence of congealing at a temperature of 5 degrees F. (—20° C.) below zero; this property denotes the absence of paraffine and belongs to a series of oils having an asphaltum base.

"'In order to determine the commercial value of the crude oil it was necessary to subject the sample to fractional distillation. Four gallons of the crude were taken for the process, and the gravity of the first two ounces of distillate that passed through the condenser was 58 degrees Beaumé. The gravity of the first eight ounces of distillate obtained was 53 degrees Beaumé, and 44.9 degrees Beaumé was the gravity of the second eight-ounce sample of distillate from the still.

"'Ten one-pint samples of the distillate were obtained, the gravities of which were as follows:

	Degrees.		Degrees.
1,	38.9	6,	29.3
2,	33.1	7,	28.6
3,	32.6	8,	27.6
4,	31.6	9,	26.7
5,	30.8	10,	25.4

"'The first and second eight-ounce samples flashed at the ordinary temperature and would be called benzine, but could not be used in the arts on account of the low gravity, and on account of the low percentage (1.56 per cent.) the yield would be almost unprofitable to collect separately.

"'For the burning oil distillate the first four pint samples were taken, the gravity being 34 degrees Beaumé, and the mixture was found to have a flash test of 85 degrees Abel, or about 130 degrees Fahrenheit (54.4° C.).

"'While the above oil would pass the trade requirements in the properties of color and fire test, the gravity and odor are so far from the requirements of a marketable illuminating-oil that under no consideration could it be sold as such, providing the illuminating oils from Pennsylvania and even Lima crudes could be obtained.

"'The intense odor of the oil would prevent its use as an illuminant, and sulphur in small quantities in crude oil imparts to the distillates a very disagreeable smell, which can only be removed with great difficulty and expense.

"'The great bulk of the distillate would be condensed at gravities below 30 degrees Beaumé, and, on account of its low viscosity, could not be used as a lubricant; and assuming the oil has no value as an illuminant and lubricant, it can only be used for fuel, and its terrific odor would prevent its use as a fuel in a thickly populated center.

"'From four gallons (32 pints) of Beaumont crude the following percentages of products were obtained:

"'One-half pint 53 degrees benzine, 1.56 per cent. One-half pint 44.9 degrees benzine, 1.56 per cent. Four pints low-gravity and bad-smelling illuminating oil, unmarketable, 12.5 per cent. Twenty-five pints fuel oil, 78.12 per cent. Coke and loss, 6.26 per cent.'"

This concludes Prof. Ledoux's report.

Postscript.

Nothing has been said in the foregoing paper concerning the commercial value of this oil, the pipe-line, tanks, etc., which have been established for its transport and export; the rapid development of the neighborhood, the numerous new enterprises in progress, etc., etc. Oil was struck in the Lucas well on January 10; and on February 20, when this paper was read at the Richmond meeting of the Institute, matters were still in the early stages of excited and incomplete development, and of many features a new description would have been required every day, so rapid were their changes. It is scarcely desirable to include in the present paper facts of later date; and a general discussion of the oil-resources of this region and their technical and commercial utilization may be with advantage postponed to a future occasion.

One exception, however, seems to be specially warranted, namely, a record of the fact that on March 3, the disaster so long and anxiously feared came upon us in a conflagration which destroyed all our workmen's boarding-houses, a considerable number of derricks and "rigs," which had been located near the Lucas well, and probably about 300,000 barrels of oil, the overflow of the first nine days after the well began to spout, and during which it was uncontrolled. We had this oil dammed against the railroad embankment about half a mile west of the well; and as the dam gave out on the third day, we had lost about 300,000 barrels before we finished a better dam. In the meantime this oil had ramified into all the drains and bayous in the vicinity of the well, and was slowly traveling towards the ports of Port Arthur and Sabine Pass. The new oil-lake itself contained the remainder of the outflow, estimated at 300,000 barrels, which was burned. The fire afforded a spectacle of unparalleled grandeur. Fortunately the wind was blowing in a direction which favored our efforts to limit the destruction somewhat. When we found that there was no possible hope of saving the oil, we started a counter-fire about a mile below the oil-lake; and when the two conflagrations met, there was a heavy explosion, which threw the blazing oil high into the air, while the earth trembled as if shaken by an earthquake. We were glad to know that our

great well was perfectly safe, having been covered with sand, in view of this very contingency.

The following is the complete record of the boring of the well, which I could not furnish at the time this paper was read:

Lucas Well, near Beaumont, Texas.

Begun October 27, 1900; completed January 10, 1901.

From. Ft.	To. Ft.	Interval. Ft.	
0	36	36	Yellow clay.
36	56	20	Coarse gray sand.
56	170	114	Blue clay, pretty hard.
170	245	75	Fine gray sand.
245	265	20	Variously colored gravel, from bean to goose-egg size.
265	317	52	Coarse gray sand.
317	352	35	Blue clay.
352	376	24	Coarse gray sand, with pyrite concretions.
376	395	19	Blue clay.
395	440	45	Fine gray sand, with lignite.
440	448	8	Warl shells.
448	508	60	Gray sand, with concretions and much lignite.
508	508.75	0.75	Soft limestone.
508.75	528.25	19.50	Gray clay and sulphuretted hydrogen gas.
528.25	529	0.75	Hard sandstone, with calcite depositions.
529	563	34	Gray sand.
563	588	25	Compact hard sand, with pyrites.
588	588.5	0.5	Hard sandstone and calcareous concretions.
588.5	601.75	13.25	Gray clay.
601.75	602	0.25	Hard sand.
602	660	58	Gray clay, with calcareous concretions.
660	666	6	White, calcareous shells.
666	680	14	Gray clay.
680	686	6	Gray sandstones, with oil.
686	693	7	Gray clay, with calcareous concretions.
693	716	23	" " getting harder.
716	718	2	Calcareous concretions, with calcite.
718	785	67	Hard gray clay, with calcareous concretions; much fine pyrite.
785	834	49	Hard gray clay, with calcareous concretions; much fine pyrite.
834	854	20	Sandstone and pyrite; pretty hard.
854	856	2	Hard rock, apparently limestone.
856	880	36	Fine oil-sand, with hard layer toward bottom and heavy pressure under it, filling casing for 100 ft. above point of drilling.
880	960	80	Hard clay.
960	1010	50	Calcareous concretions, with layers of hard sandstone.
1010	1050	40	Struck heavy gas-pressure and oil, which lasted about one hour, and then subsided.
1050	1160	110	Sand mixed with calcareous concretions and fossils.

Oil was tapped at this depth, and the 4-in. pipe used in drilling was shot out of the well, carrying block and tackle with it, followed by the column of water, etc., as above described.

The well flowed unrestrained for nine days, spouting a column of oil 6 in. in diameter from 150 to 200 feet high, and giving no signs of exhaustion until it was controlled by a gate-valve, as described above.

The hydraulic system of boring, described in the foregoing paper, proved admirably adapted for penetrating the heavy quicksands; but quite unsatisfactory as to the accuracy of the record which it permitted of the strata traversed in boring.

Chromite as a Hearth-Lining for a Furnace Smelting Copper-Ore.

BY WILLIAM GLENN, BALTIMORE, MD.

(Richmond Meeting, February, 1901.)

THAT basic slag will rapidly destroy ordinary (*i.e.*, siliceous) fire-bricks is known to every smelter; and the smelter of copper-ores in particular knows that any kind of slag occurring in his practice is destructive. From this fact arises the chief distress of those who attempt to smelt copper-ores in any manner of furnace constructed of bricks or stone, or other similar material. We have passed the fire-brick stage of our experience; and now, having entered upon the period of the water-jacketed cupola, we will employ no furnace other than that having steel walls, kept cool by water.

But, unfortunately, the bottom of a water-jacketed cupola, kept cool by another water-jacket, fails of its purpose, being thereby made so cold as to chill both slag and regulus to a degree not bearable. The situation is more or less ameliorated when the upper surface of the water-jacketed bottom is covered with fire-bricks, since, so long as they last, they prevent the molten material from contact with the cold bottom. My own observation leads me to suppose that most smelters construct cupola-bottoms of iron slabs, which are covered, to a greater or less depth, with fire-bricks. There are cupola-bottoms which

last no longer than a week; there are others, which are said to last several weeks. But the ideal bottom ought to last indefinitely.

The mineral chromite (chrome-ore) is not fusible. It is not attacked by the constituents, or by any of the fusion products of copper-ore. It is worn but slowly by the flowing of dense fluids over it. When heated and cooled, it does not become friable; nor is it subject to unpleasant explosions when quickly heated to a high degree. Hence, it ought to prove an ideal mineral for the lining of a copper-smelting cupola.

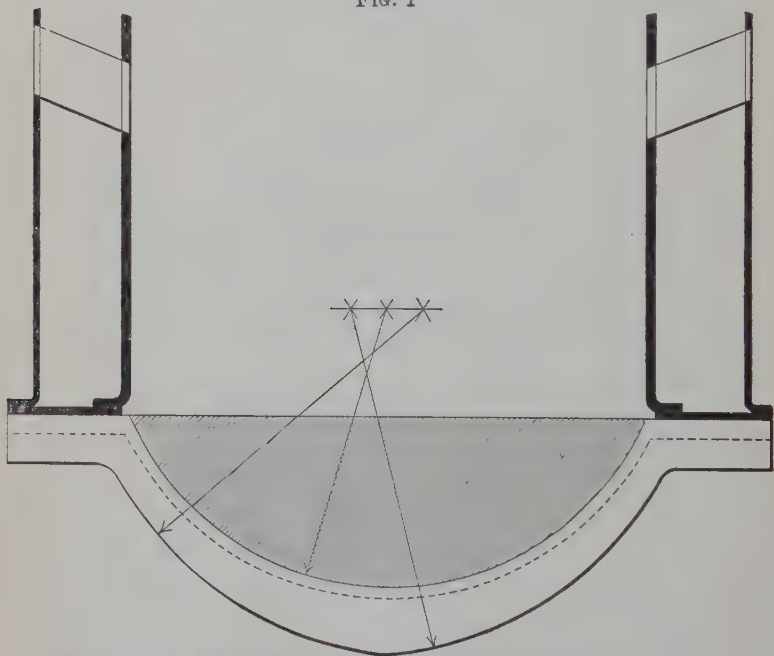
At the Elizabeth mine in Strafford, Vermont, so long ago as 1882, the writer attempted to employ it in a water-jacketed cupola copper-furnace, 48 in. in diameter. But the ore used was in the form of sand, and its grains could not be sufficiently cemented. They floated up through the matte and ran with it out of the furnace, bringing about the prompt destruction of a bottom which had been expected to prove extremely durable.

In the summer of 1899 we constructed at the same mine a water-jacketed cupola copper-ore furnace of rectangular form, the hearth of which is 36 by 120 in., having 14 tuyeres of 5-in. clear opening. Its bottom was made of cast-iron plates, held up by jackscrews, and protected by a covering, 12 in. deep, of fire-bricks. The basic slags, with the matte, would find channels through the fire-bricks, and thereafter the region of the channels would have to be kept cool by a spray of water until the end of the week, when the time came to renew the bottom. The work had come under the management of Mr. Jas. W. Tyson, Jr., who believed he could construct a chrome-ore bottom which would not float in slag or regulus, and would last indefinitely, or at least for many months. This paper is intended to recite how he proceeded, and what his results have been.

To contain the chrome-ore, and form with it the furnace-bottom, he constructed a cast-iron basin, with surrounding flange, the outer edges of which coincided with the exterior walls of the water-jacket. Fig. 1 represents a vertical section, passing through two of the tuyeres of the water-jacket, and through one of the ribs which reinforce the basin. As will be seen, the bottom of the basin is an inverted arch of 36-in. chord and 12-in. versed sine, and 1 in. in thickness (as shown by the dotted

line) except the flanges, which are 1.5 in. thick. It is in two sections, each of which is 5 ft. 7 in. long. Each section is re-inforced by three ribs, 1 in. in thickness and depth as shown in the figure, by means of two of which the sections were bolted together, with an asbestos gasket in the joint. The two outer ends of the basin were closed by segments, of the form shown by the diagonally shaded part of the figure, which were cast with the sections. The basin was supported by 10 jack-screws (not shown in the figure), placed under its flanges, and

Fig. 1



Cupola, Smelting Copper-Ore. Vertical Section, Showing Chromite Lining.

thus held securely up against the bottom of the water-jackets, leaving free for inspection the entire under-side of the basin. The chrome-ore was filled into the basin, as shown by diagonal shading in the figure, just filling the basin, and reaching no higher than the bottoms of the 4 water-jackets which form the 4 walls of the cupola. The ore used was of all sizes, from 10-in. cubes and downward, through all dimensions even to dust.

Mr. Tyson says that "the lumps of ore were fitted in as well as possible, the interstices filled with smaller lumps hammered in, and finally the cracks were filled with ground ore." He

lays stress on the fact that the ore was well compacted, and that positively no perishable cementing material was employed. Apparently, he lays stress also upon having laid a course of fire-bricks on end over the whole of the chrome-ore hearth, providing a depth of 8 in. of brick to be dissolved before the fused materials could reach it; thus permitting the hearth to heat slowly, and, as he supposes, "to glaze over" before it could in turn be attacked.

The capacity of the furnace is considerably beyond 150 tons of ore daily; and, with the chrome-ore bottom, it has made a campaign of 23 weeks so far. That is to say, it has done well for 23 weeks what a fire-brick bottom did ill for 1 week. Its present condition is not known to us, since it has not been seen since the campaign began; and, as "the basin has never been too warm to bear the hand on," we are content to let it continue its good work without interference from us.

Trusting to the continued good character of chromite under the conditions in which it is now serving in the cupola, we are about to erect a blister-copper reverberatory, the hearth and adjacent walls of which will be lined with that mineral.

Any adverse criticism relating to the form of the basin herein described, or to the disposition of the chrome-ore in it, must be made with a full knowledge of the fact that success—and, probably, eminent success—has attended both constructions. The thing has worked well, beyond any doubt. Nevertheless, I myself would venture, in the case of another furnace, to alter the construction somewhat, at the risk of making an error. The inner surface of the basin described has a radius of 19.5 in. and a versed sine of 12 in., affording space for that depth of ore in the center of the basin. It might be better to make the versed sine 6 in. (which would give a radius of 30 in. for the inner curve of the basin), and still to lay the chrome-ore to a depth of 12 in. in the center of the basin. This construction would give the chrome-ore a depth of 6 in. at each side of the basin, and it would reach that distance up into the water-jackets. The advisability of this change of construction is almost demonstrable; but this cannot be said for any alteration in the fire-brick covering laid over the chrome-ore hearth. What depth of them should be employed, or whether any covering at all is needed, is not now demonstrable. What we

do know is that Mr. Tyson laid 8 in. of fire-brick over the hearth, and that the latter apparently is as good as it was when the campaign began.

The ore now in the cupola bottom is Turkish, and contains 52 per cent. of chromic oxide. There is no apparent reason why 44 per cent. ore would not be equally serviceable; and it is more available. Such ores may be had in San Francisco of the mineral brokers, and also in the Black Lake region of Quebec. The railway-agent at Black Lake, P. Q., Canada, might interest himself in the matter, since the railway wants freight to haul.

Postscript.

(June, 1901.)

The chromite cupola-bottom above described seems to have suffered no degeneration down to this date. It has not been seen by us since the time of its construction, in 1899, because there has been no evidence that any examination was desirable.

Concerning the blister-copper furnace mentioned, I desire to say that it was not originally built precisely as above outlined. But later, its bridge-wall was constructed entirely of chrome-ore; and this has suffered no degeneration as yet noticeable. Still later, the slag-line of its hearth was built around with chrome-ore; and this also has withstood all attacks upon it.

Our experience leads us to believe that the bridge-wall of a blister-furnace should be lined with blocks of chrome-ore, compacted as far as possible, and that the slag-line of the furnace-hearth should be formed of blocks of chrome-ore about 10 in. in height. We would build the larger blocks into the walls, as best we could, and then wedge the smaller ones in among them. The work would appear rude and unskillful when looked upon after completion. Blocks of chrome-ore are rough in outline; they do not readily lend themselves to wall-building; and it is a waste of energy to attempt any shaping of them. There is no mortar, wherewith to form an inviting exterior to the work; and there is no other deceitful adjunct present.

But especially at night—when through the charging-door one sees the glowing bridge-wall as if formed of blocks of

snow or piled-up white cumulus clouds, and the whitish blocks of chrome-ore along the slag-line—the structure grows artistic, because beautifully fitting. For no matter what temperature may be attained, or how biting the corrosive and vicious slags may become, yet these chrome-ore blocks cannot be successfully attacked. When the copper has been tapped out of its hearth the furnace may be recharged immediately, while it is hot, and not (as is the case with other linings) after it has grown cold by reason of an interval of three hours, required for repairs.

Writing "in cold blood," and after making due allowance for my first enthusiasm, I feel warranted in saying that any copper-smelting cupola or blister-furnace ought to have a chrome-ore lining, as an absolute economic necessity. And I do not see why such a lining would not be the ideal thing for a converter.

The Missouri and Arkansas Zinc-Mines at the Close of 1900.

BY ERIC HEDBURG, JOPLIN, MO.

(Richmond Meeting, February, 1901.)

INTRODUCTION.

THIS paper was originally prepared as a picture of the situation presented by the mining industry referred to at the end of the year 1899; and some of the descriptions and drawings of special mines, etc., may not completely show their condition a year later. The statements made as to the cost of mining and concentration, however, still hold good. As to other general statements made in the paper, it is believed that the following additional facts cover all that is required to complete them for the additional year.

The condition of the mining industry in the Joplin district was better at the close of 1900 than at any time during several preceding years. Values seemed to have adjusted themselves, in considerable degree, to the commercial and technical circumstances, the cost of mining-supplies of all kinds had returned to a normal basis, and the product of ore found a ready sale,

being scarcely sufficient to meet the demand of manufacturers of metals. The product of zinc-ore for the year was 186,296 tons, valued at $5,711,631; and that of lead-ore was 80,478 tons, valued at $3,726,202.

The area controlled in fee or under lease by the operators in this district amounted to 106,339 acres, upon which were distributed 1103 shafts. There were in use 327 concentrating-plants, employing 597 steam-jigs; other plants, with 384 hand-jigs; 906 steam-boilers; 620 steam-pumps; 75 air-compressors; 715 steam-hoists; 521 horse-power hoists; and 380 crushers. The district employed 6688 miners, 3282 mill-men, and 1613 prospectors; or, in all, 11,583 men.

In the Arkansas field, the railroad had reached Harrison, and one car-load of zinc-ore had been shipped from the Almy mine in that district. Otherwise, I believe the statements made in this paper concerning the Arkansas zinc region remain applicable, though the present year will doubtless witness greater progress than was possible until now.

I. Missouri.

History and Statistics.

Mining has been carried on in the Joplin district of Missouri for the past fifty years. In 1849 lead was discovered in a valley near Joplin by Daniel Campbell and William Tingle. In 1853 mining for lead commenced at Oronogo (where 400 tons of ore are said to have been produced), and also at Mosley and Granby, in Newton county. At the latter place furnaces were introduced for smelting the ore into pig-lead, of which it is said that 800 tons had been produced before 1854. From 1854 to 1860 it is estimated that 300 shafts were sunk, and in 1860 there were twelve crude lead-smelting furnaces in operation, producing 4000 tons of pig-lead per annum. All the metal had to be hauled in ox-wagons to Booneville, on the Missouri river, and shipped by boat to St. Louis, where it was bought by a company owning a shot-tower, which took the entire output at $6.00 per hundredweight.

The civil war practically stopped all lead production. After its close the industry revived, and in 1871 the building of the St. Louis and San Francisco railroad through the district inaugurated a great increase in active lead-mining. Prospectors

flocked to Joplin—among whom was the late Mr. Patrick Murphy, who has been called "the father of Joplin."

In the lead-mines—especially in the deeper workings—zinc-blende was discovered, and the first shipment of that ore was made by George Hesselmeyer, who was at that time operating a zinc furnace at Potosi, Mo. I have been informed by him that he picked out of the waste-dumps at Granby some ten car-loads, for which he paid but one dollar a ton. Some of the leading miners, inferring that the stuff was worth something, determined to have it tested. Samples were sent to an assayer in St. Louis, whose returns were so satisfactory that a car-load was sent for treatment to the La Salle, Illinois, Zinc Works. The result was that agents were sent into the district to buy the ores regularly, paying from $4.00 to $8.00 per ton at the mine. The following tables give the statistics of production:

TABLE I.—*Lead- and Zinc-Production in Missouri and Kansas from the Beginning to* 1894.*

County.	Lead-Ore. Short Tons.	Values.	Zinc-Ore. Short Tons.	Values.
Jasper	233,300	$10,753,000	851,000	$18,142,000
Lawrence	25,867	1,132,946	83,711	1,240,962
Newton	77,285	3,560,400	183,000	2,096,000
Greene	94,000	444,300	5,000	123,000
Other counties	20,305	504,863	16,050	174,600
Galena, Kansas	73,645	3,765,108	145,776	2,394,604
Total	524,402	$20,160,617	1,284,537	$24,171,166

TABLE II.—*Production from* 1894 *to* 1899, *Inclusive, with Average Price Paid for Ore.*

Year.	ZINC-ORE.		LEAD-ORE.		Total Values of Both Ores.
	Short Tons.	Average Price Per Ton.	Short Tons.	Average Price Per Ton.	
1894	147,310	$19.22	22,199	$34.65	$3,535,736
1895	144,487	22.31	31,294	35.98	3,775,929
1896	155,333	22.60	27,721	32.30	3,857,355
1897	177,976	22.28	30,105	42.64	4,726,302
1898	234,445	28.42	26,687	44.74	7,119,867
1899	255,088	36.09	23,888	52.44	10,715,307
Total	1,114,639		161,894		$33,730,496

* From a pamphlet published in 1894 by J. R. Holibaugh.

The grand total is thus shown to be 2,399,176 tons of zinc-ore, and 686,296 tons of lead-ore, valued at $78,062,279.*

It will be seen from the above table that the year 1899 was the most prosperous, by reason of the higher prices paid for both zinc and lead.

In 1898 and 1899 mining property to the value of $9,712,230 was bought and recorded, and 300 concentrating-plants were erected, making a total for the district of 497. This "boom" had its effect in creating an over-production, and a general

TABLE III.—*Output of Each Camp for* 1899.

	Zinc-Ore.		Lead-Ore.		
	Quantity. Lbs.	Value.	Quantity. Lbs.	Value.	Total Values.
Galena-Empire, Kan.	128,105,210	$2,327,615	14,166,670	$345,889	$2,673,504
Joplin, Mo.	87,196,190	1,744,045	13,025,790	362,278	2,106,323
Carterville, Mo.	57,289,600	1,141,501	10,385,880	272,664	1,414,165
Aurora, Mo.	54,661,610	922,934	983,060	31,244	954,178
Oronogo, Mo.	43,772,810	887,265	412,600	10,686	897,951
Webb City, Mo.	27,252,730	517,212	1,010,280	54,365	571,577
Duenweg, Mo.	17,938,690	347,497	2,544,000	70,534	418,013
Granby, Mo.	13,281,240	235,691	827,540	34,473	270,164
Stott City, Mo.	12,839,840	271,738	394,030	10,322	282,060
Bellville, Mo.	13,208,769	260,930	145,890	5,861	266,791
Central City, Mo.	18,343,310	355,185	722,310	20,504	375,689
Cave Springs, Mo.	2,325,360	40,576	109,060	3,120	43,696
Roaring Springs, Mo.	3,539,490	120,306	397,980	10,669	130,975
Neck City, Mo.	5,200,330	105,343	877,130	22,911	128,254
Alba, Mo.	2,176,060	47,778	......	......	47,778
Carthage (and Read), Mo.	3,450,340	69,648	6,480	166	69,814
Other Camps, Mo.	10,063,380	......	1,850,160	......	230,514

stagnation in mining; and, as a consequence, the first part of 1900 witnessed a reduction in output to one-half of the previous rate, and a reduction in prices to $25.00 per ton for zinc-ore and $46.00 for lead-ore. This caused half the operators to shut down their mines, which would not pay at such prices. Most of these mines had been in operation for fifteen years, and had been more or less exhausted by the Joplin miners before their transfer to Eastern investors. The latter had expected large returns from the erection of mills, the ores having been worked previously with hand-jigs. Conditions improved, however, during the latter part of the year.

* Not including the statistics for 1900, given on page 380.

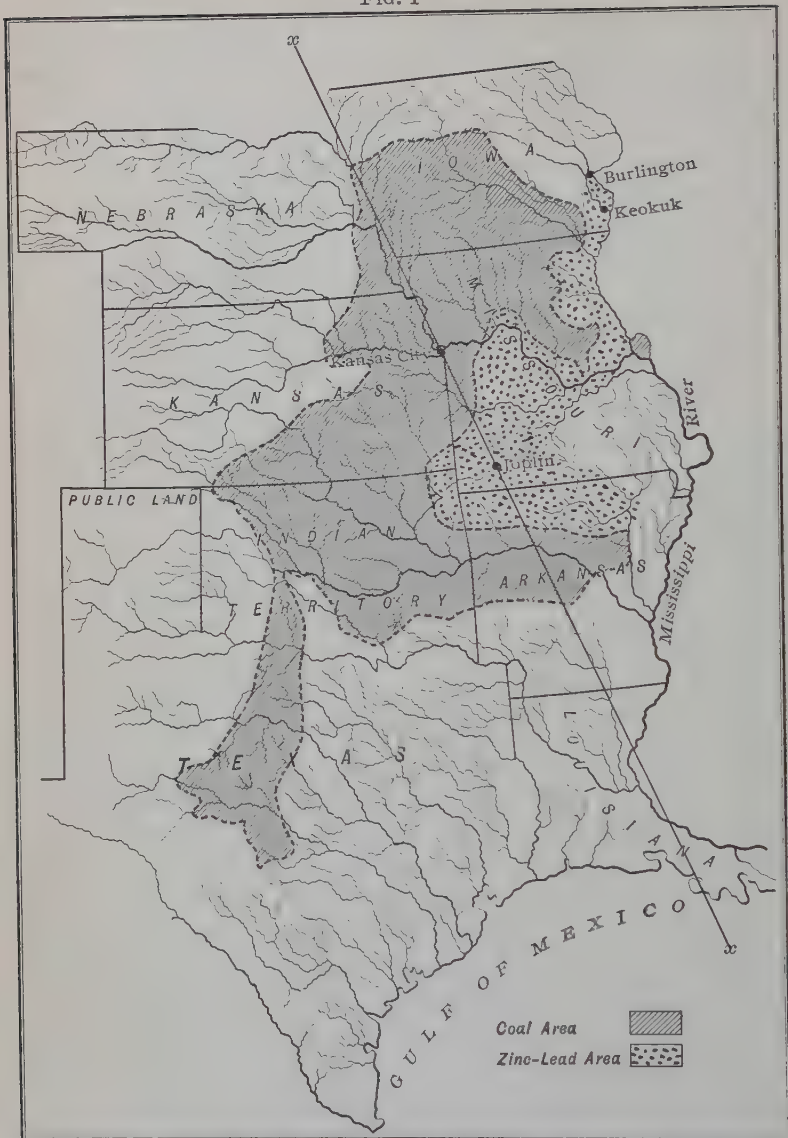
Geology.

The zinc- and lead-bearing zone extends from the SW. corner of Wisconsin, through the corners of Iowa and Illinois, then diagonally across Missouri to the corner of the State of Kansas and the Indian Territory, and thence to the NW. part of Arkansas—throughout which distance it is bounded W. and S. by the coal-measures. It is divided into several active districts, such as Shullsburg, Wis.; Galena, Ill.; Dubuque, Iowa, and St. Francis Potosi and Joplin, Mo.; Galena and Empire, Kansas; Peoria, I. T.; and Yellville, Ark. Of all these, the Joplin district is the most extensive at the present time, measuring 50 miles N. and S. and 75 miles E. and W. It is bounded on the east by the Ozark mountain uplift (see Fig. 1). It will be seen that there are three separate zones, having a relation to each other, which must enter into the discussion on the subject of geology, namely, the coal-measures, the Ozark and the zinc area.

The Coal-Measures.—The coal-field of the western Mississippi valley extends from central Iowa into Missouri, Kansas, the Indian Territory, Arkansas and Texas. In Missouri, the coal comes to the surface along the eastern border of the coal-measures, as at Crestline, NW. of Joplin, and at Lamar and Sedalia. Coal is mined at Rich Hill, in Bates county, by shafts of the average depth of 120 ft. Following the line *xx*, Fig. 1, we reach Kansas City and Leavenworth, Kan., where coal is mined at a depth of 804 ft. The present developed length of this bed is therefore 75 miles, and the dip 10 ft. to the mile. On the western edge of the Kansas coal-field the outcrop is again noticeable, as at Osage City and Scranton, 75 miles from the deepest operation. This curvature of the coal was no doubt caused by a subsidence, the center of which, theoretically, was in Iowa and Kansas, and after which the depression was filled and the surface leveled from the surrounding country.

The Ozark Region.—The area to which this name is applied is a great elliptical dome-shaped elevation, extending from the Missouri river S. to Arkansas, the highest point being at Cedar Gap in Wright county, Mo. From this point W. to Joplin there is a descent of 631 ft. in 100 miles, and from the same point southwards a descent of 700 ft. in 75 miles. There are many evidences of an upheaval in the region. It contains much

FIG. 1



Map Showing Coal-Area, and Contiguous Zinc- and Lead-Area in Missouri and Adjacent States. (From *Mines and Minerals*, Scranton, Pa., vol. xviii., p. 290. February, 1898.)

rock of older origin than the surrounding country in general, such as granite, porphyry, and Silurian limestone that is more or less fractured. Among the important minerals of economic value are iron- and copper-ores.

The Zinc-Lead Zone.—This area extends from the coal-measures on the west to the Ozark on the east, and is 75 miles wide on a line through Joplin. The formation is Lower Carboniferous limestone, with intercalated and intermittent beds of chert. It is conformable with the coal-measures, having an equal dip northwest to where it disappears under the coal.* Geologists agree that it belongs to the Burlington and Keokuk groups of the Augusta series.

The following list of localities in the three areas above described, with elevations in feet above sea-level, will show their relations to the topography: *In the coal-area:* St. Joseph, Mo. (1050); Kansas City, Mo. (1000); Leavenworth, Kan. (1025); Sedalia, Mo. (950); Nevada, Mo. (900); *in the Ozark region:* Cedar Gap, Mo. (1700); the North Arkansas plateau (1400); the North Arkansas valleys (800); *in the lead-zinc zone:* Joplin, Mo. (1060); Springfield, Mo. (1400).

Origin of the Ore.

Many theories have been advanced as to the origin of the lead- and zinc-ores, and the mode of their deposition, among which are: (1) original deposition with the rocks in a concentrated condition from oceanic waters; (2) derivation from great depth, from solutions ascending through profound fissures, and depositing these minerals in cavities, or impregnating the rocks; (3) original diffusion through the adjacent country-rock, and subsequent concentration by percolating waters (lateral secretion); (4) original diffusion through the country-rock and subsequent concentration through surface decomposition, supplemented by percolating waters; (5) original deposition with the rocks, in layers between strata of lime and chert, and subsequent fissuring of the strata; refilling of the fissures by percolating waters with zinc-blende from the broken strata at the surface; subsequent erosion of the country-rock by a large and sudden volume of water, refilling the caverns with débris derived from the coal-measures; subsequent precipitation from the ore-solutions on the contacts of the country-rock and débris-deposits; and, finally, crystallization into sulphide, covering all objects and penetrating the country-rock for some distance from the contacts.

* *Geol. Survey of Mo.* Volume on Coal, 1891, by Arthur Winslow.

The last hypothesis is here advocated as best representing the actual conditions to be observed throughout the whole field from Iowa to Arkansas.

For the last twenty years mining has been done in the hills of Joplin and at Granby upon a stratum of hydrous silicate of zinc which is, in some places, interbedded between lime and chert layers, conformably to the latter, while in other places erosion has cut down to the silicate stratum and scattered its material promiscuously over the surface.

In 1893 the writer had the opportunity to examine a similar formation, 3 miles west of Burlington, Iowa, near Starr's cave, where a bluff 150 ft. high had been cut down by the action of a creek running at the foot of the hill. In this hill a zinc-mine had been opened; but the ore had proved too low in grade for profitable working. This hill, eroded on three sides, consisted of surface-clay and limestone boulders for 70 ft., with some chert bands intermixed; then a 7-ft. stratum of zinc, below which was a chert bed extending down to the water-level. Above the silicate there was some sulphate of lead (anglesite) in sheet-form. The whole formation was horizontal. On the top of the hill a shaft had been sunk 100 ft., penetrating the same formation as that shown in the bluff. Samples of the vein in the shaft assayed 40 per cent. of zinc; and samples from the exposed bluff assayed 5.05 per cent.

The chert bed below the zinc silicate contained numerous minute pockets and crevices filled with zinc-blende and calcite, indicating very plainly that a solvent leaching through the silicate bed had deposited its mineral contents, in descending through these crevices and openings, in the form of crystalline sulphide, wherever the conditions were favorable. In this case the downward percolation was favored by the attitude of the bluff and the immediate drainage-outlet offered by the creek at its foot.

Evidently the silicate stratum was originally laid down with the country-rock (and afterwards, possibly, somewhat altered in place) and the limestone nearest to it became charged with the mineral from the contact.

In my opinion, this stratum formed the shore-line of the Carboniferous sea, and its silicate of zinc was formed from the carbonate by the exchange of carbonic acid (of which it still contains 20 per cent.) with silicic acid.

The Fissuring Process.—In places where the original country-rock has not been removed by erosion, and where (as on the Arkansas plateau) the outcrops are not obscured by vegetation, a system of fissures can be observed at the surface. These fissures stand perpendicular to the stratification, and have been followed, here and there, to the depth of about 250 feet. They have a NW.–SE. strike—called by the Missouri miners the "ten o'clock range"—and the system extends, parallel with the Ozark uplift, from the border of the coal-measures to North Arkansas. It was caused, no doubt, by the uplifting of the Ozark, assisted by the sinking of the coal-measures.

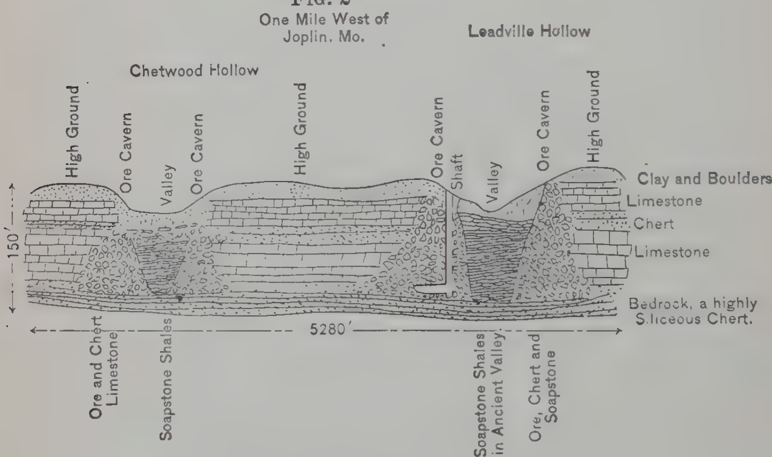
In this process the zinc silicate layer was cracked and shattered, and furnished the material for solution, downward percolation and re-deposition as sphalerite, with calcite, in the fissures below. This relation is plainly visible in many places, especially in Arkansas, where exposures in the hillsides and in the valleys present the former order of strata as they existed, no doubt, throughout the whole region, prior to the obliteration due to erosion, and at a period when the surface was comparatively unbroken prairie-level.

The Period of Erosion.—The special erosion here meant was apparently caused by the liberation of a large body of water and the establishment of a new drainage-outlet for a former water-shed area, resulting in a strong and continuous torrent, which descended upon the southwestern zinc-region in a course parallel to the Ozark ridge and the fissure-system. It carved channels to the depth of 150 ft. in Joplin and vicinity, and 500 ft. in the table-land, Arkansas, where the current was very swift, leaving bluffs of corresponding height on both sides, and carrying the débris towards the Gulf of Mexico.

There is evidence of the existence, before this event, of an inland sea, or vast lake, which covered the "Bad Lands" of the Dakotas; and it also appears that near St. Joseph, on the Missouri, there was a natural dam, holding back this vast volume of water. The breaking of this dam would, of course, flood the country; and although the first violent overflow may not have accomplished the carving of the surface, it probably established the main new drainage-channels, or largely deepened the shallow and local depressions already existing, thus concentrating and directing the effects of the subsequent less

violent erosion.* At Joplin, this process cut below the zone of the fissures, stopping at a highly siliceous chert "bed-rock." The border of the coal-measures, being much softer, was washed down and deposited in the newly-made caverns and ravines, thus rendering the surface comparatively level again. (See Fig. 2.) In this district, therefore, the effects of the special erosion-period are marked by underground exploration. Such is not the case, however, in the southern counties of Missouri and in northern Arkansas, where the ravines remain, except for a few feet of alluvial deposit, open to the depth of the great erosion.

FIG. 2



Section One Mile West of Joplin, Mo.

Precipitation of the Ore.—The débris from the coal-field, which now lies in irregular deposits all over the district, contains, besides occasional pockets of coal and patches of more or less bituminous shale, a large amount of pyrite. The decomposition of the latter acidulates the percolating surface waters, which, by virtue of the sulphuric acid as well as of the free carbonic acid they contain, attack the country-rock (principally limestone) along its contact with the cavern-fillings;

* In fact, the assumption of such an initial flood is not necessary *a priori*, and if the indications of it which have been mentioned should be proven illusory, or deemed inadequate to establish its occurrence, the present topography could still be referred to a long erosion, not thus originated or determined. The main point is, that the erosion of that period exposed the pre-existing succession of strata, including the zinc-bearing layer already mentioned.

dissolve the lime; break down the chert; and dissolve the silicate of zinc. The re-formation of calcite in the fissures, etc., is not difficult to understand, at least hypothetically. The re-crystallization of zinc as sulphide presents a more obscure problem, upon which the writer will not here enter. It may be pointed out, however, that the presence of bituminous matter in abundance affords a reducing agency adequate in amount to this reaction. Moreover, the decomposition of pyrite to iron oxides, etc., is known to yield often, as a residual product, native sulphur, which is a reducing agent. It should be added that, according to the writer's observation, the deposition of zinc sulphide has not taken place where the caverns, etc., are open and exposed to atmospheric influences. The reducing-agent which formed the sulphides seems to have been efficient only where the oxidizing effects of the atmospheric and of meteoric and acidulated waters had been, as it were, locally exhausted.

The production of these sulphides from the overlying silicate deposits, therefore, cannot be pronounced impossible, though it may not be possible, as yet, to prove positively each step of the process. But the only alternative seems to be the deposition of the sulphides from waters ascending through deep fissures—alkaline solutions, for example. Against this hypothesis we have the strong objection that the fissures containing the sulphide-ores apparently do not extend to great depth, but stop with the lower limit of the special formation in which they occur. And if it be that these "gash-veins," cavernous-deposits, contact-deposits, etc., are merely collateral bodies, connected indirectly with a deeper source, we must point out that the system of shallow fissures above described has been shown by all experience thus far to be the main feature of the metalliferous field. It would be strange if a mere accessory phenomenon should thus control all the facts discovered in actual exploitation.

The developed mines of this region follow in their relative position, as in their individual structural features, the NW.–SE. trend of the fissure-system. They lie in parallel belts, always beginning on the NW., near the coal-field.

Thus, we have on Spring river, in Kansas, the Grace Clark mine, and, in succession to the SE., the Empire, Galena and

Riceville mines. The next belt, two miles to the E., and parallel, contains from NW. to SE. the Badger, Smithfield, Bellville, Cave Spring, Central City, Roaring Springs and Spring City mines. The belt containing the Lehigh, Tuckahoe, Joplin, Rex and Saginaw follows; 4 miles E. of this is the belt of the Poundstone, Oronogo, Webb City, Carterville, Duenweg and Granby mines; and again, 4 miles further E., lie in a similar series the Neck, Alba Macy, Pleasant Valley and South Carthage mines. The Read, Wentworth, Stott City and Aurora mines follow similar trend, which extends into Arkansas.

An observer can stand at Oronogo and see the mill-chimneys located in a straight line to Duenweg, 8 miles away; and similar perspective views can be had at Lehigh and Joplin.

The zones thus occupied by the mines are, of course, not continuous ore-deposits. They contain ore-bodies of irregular extent, and all of them present great masses of barren shale and soapstone. Moreover, the intervals between them, having an aggregate area of three-fourths of the whole mineral district, seem to be barren. At least, vigorous prospecting has failed to develop in them any valuable deposits. According to the statistics of the Drill-men's Association, there were 600 prospecting drills in operation during 1898 and 1899, making each 200 ft. per month—giving a total of 14,400 drill-holes of the average depth of 200 ft. Yet, with the exception of a few extensions of old mines, no new camp was developed as the result of these explorations.

These facts indicate strongly that the fissure-zones were the main localities of ore-deposition.

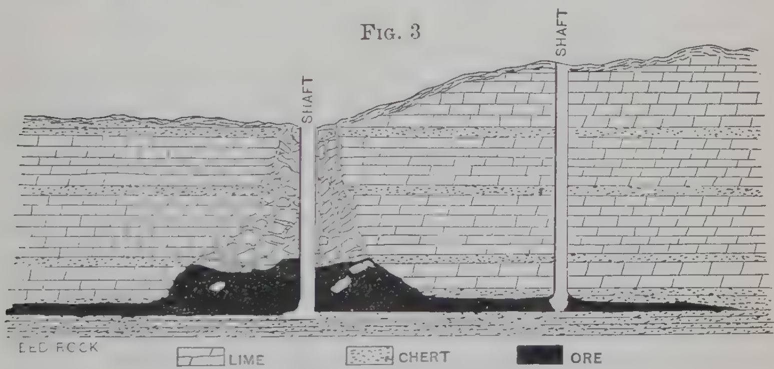
Direct evidence as to the filling of these fissures by secondary processes will be given below in the special description of the Arkansas field, where, for reasons already explained, such evidence is more clearly and extensively exposed. But on the Bonanza claim, near Galena, Kansas, and at the John Jackson mine, near Joplin, indications of the same process may be seen.

As to the re-filling, with débris from the coal-measures, of the channels of preceding erosion, the section near Joplin (Fig. 2), and that of the Eleventh Hour mines at Carterville (Fig. 3), may be taken as evidence. In the latter case the eroded chan-

nel was narrower at the surface, and widened towards the chert rock at the bottom, which resisted further erosion. As the figure shows, the solutions from above, unable to penetrate this siliceous rock, worked along the contact horizontally, dissolving out the overlying limestone and depositing the ore in a sheet, from 6 to 15 ft. thick, to the distance of 1000 ft. from the main channel. At the neighboring Get There mine several shafts have been sunk 150 ft. through solid limestone and chert strata to this sheet-deposit.

As to the presence and action of acidulated waters and the precipitation of sulphides, there is significant present evidence. All the mine-waters are so strongly acid that it is difficult to protect pumps and pipes. In some cases brass has been em-

FIG. 3



Eleventh Hour Mines.

ployed as a more resistant material. The deposition of blende, galena and calcite is undoubtedly still going on. At Granby, miners' picks, left underground in 1860, have lately been found covered with crystals of both galena and blende. In this case either the organic material of the wooden handles or the iron of the picks themselves furnished the reducing-agent. But any other form of organic matter would probably act in the same way.

As a general rule, the lead-ore is found above the blende, or scattered through the upper zone of the deposit of the latter. In my judgment, the mode of deposition was the same for both, but the lead was carried down and crystallized later. In this connection, the observation made in Iowa, and noted on a previous page, may be significant, namely, that the stratum of anglesite lay above that of zinc silicate.

The Deeper Run of Ore.—Much has been said of late concerning a possible deeper ore-bearing horizon; but, the deepest mine-workings being at present less than 250 ft. from the surface, there is nothing to be learned from them under that head. The only information known to the writer, which bears upon the subject, is the record of the holes drilled by Crossman Brothers,* which may be summarized as follows:

Record of Drilling.

No. of Holes.	Depth.	No. in which Ore was Found.	Remarks.
500..........	50	15	
450..........	100	36	
400..........	120	100	
125..........	250	42	
100..........	300	0	
25..........	400	0	
12..........	500	*a.* 9	*a.* From 40 to 60 ft. of lead- and zinc-ore.
8..........	600	4	
8..........	700	0	
7..........	800	0	
6..........	900	3	
6..........	1,000	0	
2..........	1,100	*b.* 1	*b.* Zinc-ore from 1075 to 1100 ft.
2..........	1,200	0	
2..........	1,400	0	
1..........	2,005	*c.* 0	*c.* Flint and limestone, as at surface.

Of the 12 holes put down to 500 ft., 9 found ore under some 260 ft. of rock. This is rather a small number of holes to establish a general proposition; and the nature of the evidence is not altogether trustworthy, because it was furnished, not by solid cores from the diamond drill, but from the débris produced by the "churn-drill;" and, since (according to the general practice in solid rock) the holes were probably not "cased," the constant jarring of the churn-drill might easily have loosened particles of soft ore from the upper ore-horizon, which might thus have "salted," so to speak, the material brought up from lower depths. The great range of depth (from 40 to 60 ft.) through which ore-bearing material was thus reported tends rather to increase than to dissipate this suspicion.

On the other hand, be this as it may, we have reason to be-

* Published in the *Mining Herald.*

lieve that some ore exists at deeper horizons, since other drill-contractors have reported the raising of "ore-slimes" from depths of 500 to 600 ft. But there is nothing to show the existence of paying ore-bodies at any such depth. The traces of ore may be due to the greater extension in depth of some narrow fissures, but the main concentration of ore seems unquestionably to have a lower limit at the "bed-rock," 250 ft. or less from the surface. This was the limit of the erosion already described, and consequently of the occurrence of caverns. Even if there had been a second layer of silicate-ore, below an interval of 200 ft., underlying the upper ore-horizon, there would have been no caverns or spaces caused by erosion to receive ore-deposits; and the result of all the processes above described would have been a dissemination of mineral, limited in extent and in degree of concentration, through a deeper-lying strata.

This stratum, by reason of the general NW. dip of the formation, would approach or reach the surface somewhere south of Granby and Aurora, where it would be enriched by the scattered ore from the upper horizon, and possibly also concentrated through the action of surface-decomposition and erosion. Thus, at Granby, where the upper ore-horizon has been mined for years within 60 ft. of the surface, the Mascott and other mining companies have sunk shafts to 160 ft., encountering a large body of disseminated zinc-blende, entirely different from anything from above. This stratum is, very likely, the one which supplied the filling of the fissures of the Arkansas field, where the lower horizon referred to would be found near the top of the hills (see Fig. 4).

Future Mining.

Prophecies of the future of any mining district are, as a general rule, untrustworthy; but in the Joplin field, for instance, long and extensive exploration and underground development have established with considerable certainty the side-limits of the ore-zones, the barren intervals between them, and the position of the underlying bed-rock, so that some forecasts are reasonably practicable.

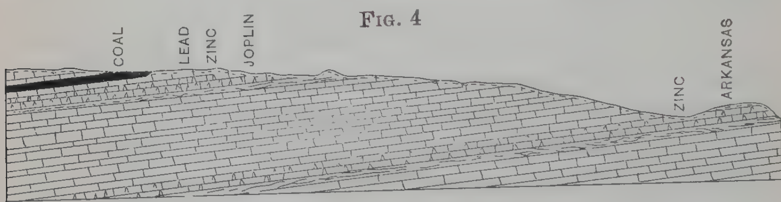
Galena.—This is no longer the camp that it was three years ago, when the weekly production was worth $50,000—reduced by the end of 1899 to $15,000, and now about $20,000. The ore-bodies were from 6 to 20 ft. in vertical thickness,

easily mined, and soon exhausted; and as they constituted mainly a large cavern-deposit, while the place is encircled by the coal-measures (see Fig. 1), the prospect for valuable extensions is not favorable.

Joplin.—The mines of this district are more scattered. Many of the ore-deposits are of comparatively recent discovery, and will continue for some time to be productive. Moreover, even in the exhausted and abandoned mines there is a chance of discovering, by further exploration, extensions of the ore-deposits.

Webb City and Carterville.—These camps contained the largest deposits of zinc-ore in the region. Mining has been continuous since 1876 on ore-bodies 100 ft. in vertical thickness, and often 1000 ft. wide, upon a belt 4 miles long. This ore-formation, discovered in open "boulder-ground," was cheaply mined, and was nearly exhausted five years ago, but operations on a small scale have been revived and continued since.

Fig. 4



North and South Section through Joplin, into Arkansas.

Present mining is conducted extensively upon a sheet of zinc-blende, with streaks of galena, resting on the rock-bed (see Fig. 3). This deposit is very hard, requiring the use of much dynamite in mining; and the cost of mining is $20 per ton of clean concentrates (the material in place averaging 6 per cent. of zinc and 1 per cent. of lead). Consequently it cannot be mined with profit (above cost and royalty) unless zinc is worth $35 to $40 per ton—or, in other words, concentrates are salable at $30 per ton.

The region is favorably situated for the discovery of new and valuable extensions of the ore-deposits; but the present prosperity must depend upon the market-price of zinc-ore.

Neck City, Alba and Carthage.—These camps are new, and have thus far been proved to contain large deposits, approaching in thickness those of the Webb City and Carterville camps, as first developed. Since the ground is only of medium softness,

and does not require much timbering or blasting, these deposits can be profitably mined when zinc-blende is worth only $18 per ton.

Read and Wentworth.—These camps are beginning to develop an important mining center; with a promising outlook.

Aurora and Stott City.—These are of comparatively recent origin as mining camps, but yield already a large output of ore, and present abundant indications of future prosperity.

Prospecting. — Even assuming that the older mines of the region are becoming exhausted, at least so far as known ore-reserves are concerned, we may expect a further continuance of productive industry by reason of the fact that many intervals still remain along the ore-zone which may be profitably prospected. Past experience suggests, to guide the prospector in the selection of a place for his operations, some principles which are practically worthy of attention, though they may not be in all cases fully established as the result of theoretical investigations, or traced in connection with geological and chemical agencies.

For instance, to present the best chance of future productiveness, a new location should be within one of the known productive zones, and at the foot of one of the hills sloping N. or NW.*

Many productive mines—such as the Empire, South Side, Bloomington and Battlefield, at Galena; the Badger, Klondike, Rabbit's-foot, Scotia, Chetwood and Leadville, in Joplin; the Boston, Little Circle, Center Valley and Connor in the Webb City and Centerville district—are thus situated. On the other hand, the S. and SE. slopes prove barren,—suggesting that the ore-bearing solutions followed the original trend of the erosion-channels, and deposited their mineral contents against the obstructions and the eddies, much after the manner of the deposition of gold in the gravels of the ancient river-beds of California.†

---

* Or it may be at the top, provided that the surface undulations, etc., indicate that the hill is simply the later accumulation filling and covering the hollow of an erosion, now underground.

† This analogy is, of course, not perfect, since the deposition of native gold is effected by the operation of specific gravity only, whereas the ores here under discussion are chemical precipitates. Yet chemical precipitates, once formed, may be carried in mechanical suspension, and finally deposited where obstructions,

II. Arkansas.

In view of many newspaper and other reports concerning the development of deposits of zinc-ore in northern Arkansas, the writer made a personal investigation of the region, with the results here given.

Geography.

The district, in the northwest corner of Arkansas, covers five counties,—Carroll, Boone, Marion, Searcy and Newton,—which are included in the so-called Blue Ozark range. It adjoins the Missouri line on the north and the Indian Territory on the west, being 150 miles wide from E. to W. It is situated on the tributaries of White river, a stream navigable for four months in the year by light-draught steamboats plying between Batesville, on the railroad, and Buffalo City, in Marion county. The country is broken and hilly, the highest points being 1400 feet above tide-level, and denudation having carved out the valleys and ravines to a depth of 700 ft. The most important towns in this region are Eureka Springs, Harrison and Yellville; the nearest railroad is the St. Louis and Northern Arkansas, at Eureka Springs, which makes connections with the St. Louis and San Francisco at Seligman, Mo. At present the railroad company is building an extension to Harrison and Little Rock, which is expected to be in Harrison early in 1901. The principal resources of the region are an abundance of oak and walnut timber, fine building-stone and marble, lead and zinc. The plateaus and valleys are cultivated.

History.

Edmund Jennings, coming a hundred years ago from Tennessee, lived fifteen years among the Indians of this region; and, when he returned to Tennessee, had marvelous tales to tell of the forests and caves, springs and rivers, and game in what he termed the country of the "Six Boils," meaning, no doubt, the Lip Springs at Eureka. His stories of the Ozarks fired the minds of his listeners, and immigration began almost as soon as the United States had acquired the territory by the Louisiana

eddies, or other conditions diminishing the speed of the ore-bearing current, may favor their accumulation. The acidulated waters flow from the coal-measures in a SE. direction, and follow the original fissure-trend underground.

purchase. Adventurous Tennesseans poured into the Ozarks, and the Osages and Delawares were crowded out.

In 1857 and 1858 the distinguished pioneer and geologist, David Dale Owen, made reconnoissance of the northern counties of Arkansas;* but nothing in the way of mining developments was then attempted.

The first active mining was inaugurated by a Chicago company, which in 1875 erected a smelter at Calamine, Sharp co., for the reduction of carbonate ores. The enterprise was not successful, and was abandoned.

In 1880 a company of Joplin men erected at Lead Hill a lead-smelter, which ran for a short time. The next development of note was made in 1882, when the Carthage and Arkansas Mining Co., organized by the writer to operate lead-mines in Newton co., built a smelter and laid out a town at Boxley. Operations were continued for a year, during which period five car-loads of pig-lead were shipped to St. Louis by way of Eureka Springs; but the long wagon-haul of 95 miles to the nearest railroad proved a fatal disadvantage, and the project was abandoned until better conditions of transportation could be enjoyed.

The Morning Star mine in Marion co. was discovered in 1884. In 1893 some ore from this mine was taken down the river and shipped as an experiment, and it is reported that the ore brought $16.50 per ton. Since that time the mine has shipped about 1000 tons, including the monster chunks of zinc carbonate to which was awarded a gold medal at the Chicago Columbian Exposition of 1893.

Geology.

The zinc-bearing area of North Arkansas is a part of the Missouri district (see Fig. 1). It is bounded on the W. and S. by the coal-measures, and on the N. and E. by the Ozark uplift. The zinc-bearing formation dips N. and correspondingly rises towards the S., so as to place at the tops of the hills, in Arkansas, the strata which are found at Joplin 500 ft. below

* *First Report of a Geological Reconnoissance of the Northern Counties of Arkansas, made during the years* 1857 *and* 1858. By David Dale Owen, Principal Geologist, Little Rock, 1858.

the surface (see Fig. 4). This formation is recognized as the Upper Silurian. The section is as follows: Surface material, 10 ft.; sand-rock, 4 ft.; marbleized limestone, with intermixed chert bands or layers, 500 ft. The region was eroded to much greater depth than the Joplin district, by reason of the greater swiftness of the eroding currents, which is noticeable to this day in the streams now active. The eroded caverns and ravines remain open, unlike those of the neighboring country to the north, where refilling has taken place. In this region it can easily be seen that the largest fissure-deposits have been eroded and washed away, leaving here and there a few patches adhering to the hillsides. In many instances the whole of the hanging-wall and part of the vein-material have been cut down, leaving the foot-wall with some ore upon it exposed to full view. In some instances this phenomenon is shown on both sides of the hill, which would indicate to a novice that the ore extends through the entire hill, as in Fig. 5; but on examination we find that this is not the case, since the strata are horizontal. The outer crust of the ore thus exposed has been changed from sulphide to carbonate.

Mineralogy.

A collection of the Arkansas minerals, owned by the Arkansas *Times*, contains 44 varieties of Arkansas zinc-ores, ranging in color from a dense black-jack to a snow-white zincite. The Owen expedition discovered here a kind of zinc-ore which it is said was not classified in the catalogues, and believing that they had found something entirely new, they named it marionite, in honor of the county in which it was found. Since that time a new species has been found and named Brannerite, in honor of a former State Geologist who had great faith in the future of North Arkansas. Brannerite is an anhydrous carbonate of zinc, containing 70 per cent. of zinc, 24 of carbonic acid and 3 of silica. Marionite contains 73 per cent. of oxide of zinc, 15 of carbonic acid, and 11 of moisture, and is the reverse of Brannerite, being a hydro-zincite. Its color is light gray. Much Smithsonite also is found in Newton county. Sphalerite is the most common zinc-mineral, and is found in the fissures not exposed to the atmosphere, and, to some extent, disseminated through the wall-rock for a limited distance. It contains 65.5 per cent. of

metallic zinc, and holds that average much more uniformly here than in the Joplin district.

General Mining Developments.

Upon entering the State by railroad the familiar sound of dynamite-blasts is heard at Gaskins Switch, where the Fowler mine shows a 12-in. vein of lead-ore. The location is highly favorable to economic working, being on the railroad and in the suburbs of Eureka, a town of 5000 inhabitants.*

The latest mineral discovery in this vicinity was made in driving the new railroad tunnel through King's mountain, by which a 12-in. vein of zinc-blende was cross-cut.

From this place the stage goes 40 m. E. to Harrison, the center of the mining region. The town has a population of 2500, and is furnished with all modern conveniences. Here the explorers are fitted out with pack-animals and provisions for the surrounding camps.

The principal mining centers are Marble City and Mount Hersey to the south: Lead Hill, Sugar Orchard and Dodd City to the northeast; and the Crooked Creek Camp to the east.

Some 25 m. further E. is Yellville, situated in a valley surrounded on all sides with mountains, and 10 m. SE. of this place is the Rush Creek district, where the Morning Star is located. It will be seen from the general map of the district that the camps mentioned are located at the head of a system of creeks which have cut down into the mountain so as to expose the ore, where it is now easily found. It is my opinion that better veins exist in the level country and in the axis of the mountains.

Developed Mines.

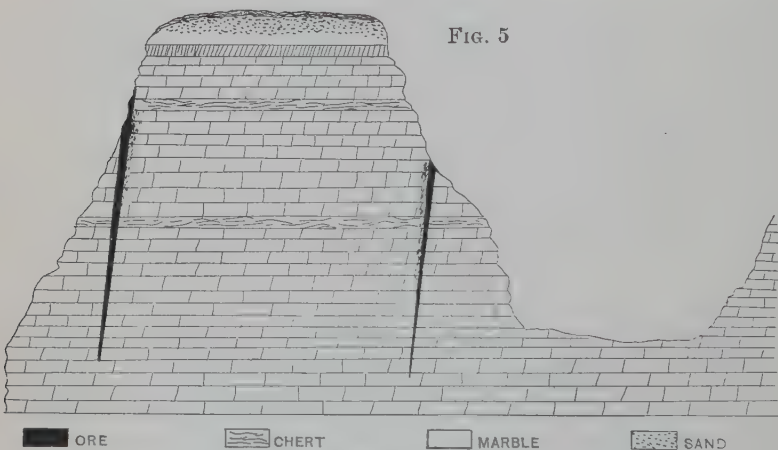
Rush Creek District.—Here are the Morning Star, Silver Hollow, Red Cloud, White Eagle and Maryhattiana. On a transverse vein are the McIntosh, Georgetown, Cook and Lion Hill mines. The Morning Star's ore-deposit (Fig. 5) is a gash-vein, laid bare by erosion at the surface on the hillside in which the blende has changed to a carbonate. The hill is 500 ft. high, and the ore crops out about midway. By blast-

* These are mostly invalids, drawn to this place by the fame of the Eureka springs.

ing out the top of the remaining limestone hanging-wall, the vein was exposed. A cut has been driven across it which is now 30 ft. high and 70 ft. wide. This cross-cut, at right angles to the strike, went through the ore and penetrated the wall-rock beyond, showing that the ore does not extend through the hill. A shaft has been started on the vein in the bottom of this cross-cut, which shows both walls. This company owns an old-fashioned concentrating-mill, of about 50 tons' capacity, which is connected with the mine by a gravity tramway.

The White Eagle mine is located on a ravine transverse to the main valley. Here a shaft is going down on a vein 10 ft.

FIG. 5



Morning Star Mine.

wide, and parallel to the axis of the hills. In my opinion this mine is very favorably located.

The McIntosh mine is one of the striking examples of erosion in Arkansas. It is located half a mile below the Morning Star, and was recently sold to an eastern syndicate, which has just had a 150-ton concentrating-mill erected. The mine is very similar to its neighbor, the Morning Star. The ore outcrops about half way up the hill, over which the water from the crevices of the limestone above has passed for ages, leaching the blende, which in part has been precipitated as a carbonate on the hillside below the outcrop. A small cut in the ore, run at right angles to the axis of the hill, discloses the

solid lime formation, and indicates very plainly that the ore in sight is nothing more than a coating on the hillside, left from the erosion of a larger body.

The Lion Hill mine, located near Buffalo City, has a 75-ton concentration-plant in operation, milling a low-grade zinc-blende mixed with carbonate, which is mined out of two openings on the hillsides. All other so-called mines in this district are mere prospects.

Dodd City District.—Here are a number of developments, such as the Tallow Clay, Iola, Markle, Albert and Jessie, Pilot Rock, McKinley, Ben Harrison and others, but there is nothing as yet that can be classed as a mine.

Bear Hill.—Here the New York Zinc and Lead Co. has sunk a shaft on a true fissure to the depth of 100 ft., and at the 35-ft. and 85-ft. levels drifts have been run on the strike of the vein. In the latter, the fissure and its contents of ore can be seen and traced along the roof and in the floor as far as the working goes. The vein strikes NW.–SE.; the fissure widens and pinches alternately, but the seam of blende is persistent, and impregnates the wall-rock each side of the vein, making an average pay-streak of 2 ft.

Sugar Orchard District.—These mines, located in a basin on the line between Boone and Marion counties, comprise the Frisco, Jackpot, Minnie Lee, and others. The first discovery of ore was made in the Frisco and the Jackpot by cross-cut in the hill. Several shafts since sunk to a depth of 75 ft., in the valley proper, have encountered a mass of loose boulders and earth, with interspersed zinc-blende and carbonate, which were no doubt eroded from the surrounding hills and carried down into the Sugar Orchard basin.

The Crooked Creek Mines.—The Denison Zinc Co. has recently completed a mill of 100 tons capacity, and the Almy Mining Co. contemplates building one at an early date. Both of these mines are open-cuts, similar to the Frisco and Jackpot.

Mount Hershey District.—Here the Masmee Mining Co., capitalized at $1,000,000, has acquired 1100 acres of land. Several tunnels have been opened on this property, of which one in particular shows a 12-ft. deposit of blende that will yield 10 per cent. of marketable concentrates.

III. Methods and Costs of Mining and Milling.

For full details upon this subject, I would refer to my articles, published in *Mines and Minerals.** Without repeating the descriptions there given, I will simply add in this place some summary statements as to the methods employed, and their cost.

Mining Methods.—The ground is first explored by drilling to the depth of, say, 200 ft., for which purpose the ordinary oil-well churn-drill is better than the diamond-drill, because of the broken condition of the ground and the hardness of the chert beds. The position of the ore having been thus determined, a shaft is sunk to it, usually from 5 by 5 to 6 by 12 ft., inside the timbers. The contract price is from $4 to $25 per ft., according to the hardness of the ground. In hard ground, no timbering is used. Where the shaft must be timbered, this is done either with 4-in. round oak poles, notched and stepped in the corners, or with 2-in. planks, 4 or 6 in. wide. Water is usually handled with a common single-stroke lift-pump, of 6 to 14 in. cylinder-diameter and 3 to 6 ft. stroke, operated, together with the hoisting-engine, by steam. In this preliminary stage of mining, the wages paid are $2 to $3 for 9 hours' work.

The method of stoping employed depends upon the nature of the ground. In hard ground, not fissured, underhand stoping is frequent, drifts being run from the shaft along the top of the ore-bed, and the stopes being carried down from these. Each stope is about 12 ft. high.

The cost of mining in hard ground, on a scale of, say, 75 tons per day, is as follows:

Mining-Cost in Hard Ground.

Employees.	Wages per Day.
1 Underground boss,	$2.50
2 Miners at $2.25,	4.50
2 Miners at $2.00,	4.00
2 Shovelers at $2.00,	4.00
1 Hoister,	2.00
1 Engineer,	2.50
1 Blacksmith,	2.50
1 Superintendent,	4.00

* Vol. xviii., pp. 289, 392, 482, 554 (1898).

Supplies:	
Dynamite,	6.50
Fuel,	4.00
Oil, etc.,	2.50
Total,	$39.00

or, for 75 tons per day, 52 cents per ton.

In ground which is hard enough to stand while a cut is made 10 ft. ahead, but then requires to be timbered, it is best to put mud-sills under each set of timbers, which can be caught up from below when the next floor is stoped. This can be done until 4 or 5 sets of timbers have been placed on successive floors, making of the original drift a stope 60 ft. high. In case of a threatened creeping of the ground, cribs are built to permit the closing of the stope.

In mining very soft ground, the drift is carried only 8 to 10 ft. high, with "fore-poling" in roof and sides, and as each level is worked out, the floor is covered with long logs, laid in the direction of the drift, after which the supporting timbers are destroyed with dynamite, and the whole level is made to cave upon the floor—the ground for 30 ft. from the shaft having been protected with solid cribbing. Below this caved ground, the next level of the stope can then be run, having as its roof the log-floor previously laid, which can be caught up with new timbering.

In most cases, the ore occurring in soft ground can easily be cleaned on hand-jigs without such previous crushing as the hard ore requires.

A shaft 150 ft. deep, with pump and hoist, hand-jigs, and all necessary tools, costs from $3000 to $4000. After this outlay, the underground work is expected to pay for itself.

Concentrating-Methods.—In the early days of shallow mining the ore was found imbedded in clay, and needed only to be washed clean by throwing a few bucketfuls of water over it. The first zinc-ore shipped consisted of large lumps found among the lead-ores, and required little dressing to make it salable. But as the demand and price increased, the finer stuff began to be saved by treating it with screens, sluices and hand-jigs, such as are still used by small operators. These jigs are about 6 by 6 ft. in size, and 3 ft. deep, containing a suspended jig-box 2 by 5 by 2 ft. The bottom is either

of wire-screen or small grate-bars. The jig is operated by means of a lever, or jig-pole, 18 ft. long. An expert workman can separate a charge into gangue and ore in from 5 to 8 minutes.

The treatment of 30 tons of crude ore per day of 9 hours requires 5 hand-jigs if the ore is wholly blende, or 6 if both blende and galena are present. Four men operate 4 "roughing"-jigs, each handling about 8 tons per day. One man separates in another jig the galena and blende produced by the four, and a sixth man cleans the "fines," which have passed through the jig-bars and settled in the bottom of the outer box. The cost is as follows:

Cost of Hand-Jigging.

Employees.	Wages per day.
2 men at grizzlies and dump,	$3 00
4 men jigging at $2,	8 00
2 " " " $2.50,	5 00
Handling of waste rock,	1 50
Total,	$17 50

or, for 30 tons, 58⅓ cents per ton. Adding 52 cents for mining, we have $1.103 per ton of crude ore mined and cleaned.

At many mines where crushing is not needed, the Robinson jig is used as a substitute for a part of the hand-jigging, the operation being completed by hand. The cost of this method is:

Cost of Mechanical Jigging.

Employees, etc.	Wages per day.
1 man at screen,	$1 50
1 " " jig,	1 75
2 men " the finishing hand-jig,	4 00
Fuel,	1 50
Oil,	0 50
Wear and tear,	1 00
Total,	$10 25

This produces 50 tons per day, and the cost per ton is only 20.5 cents, or, if handling of the waste rock be added, 23.5 cents per ton.

A complete mechanical concentrating-plant, including crushers, will treat 100 tons of crude ore daily for $22.75. The cost of such a plant would be about $8,000.

Investigations of Magnetic Fields, with Reference to Ore-Concentration.*

BY WALTER R. CRANE, LAWRENCE, KANSAS.

(Richmond Meeting, February, 1901.)

CONTENTS.

THE form and strength of magnetic fields have attracted much attention, especially in connection with the designing of dynamo-electric machinery—an art which has been revolution-

* This paper is a thesis presented by the author for the degree of Ph.D. at Columbia University, New York City.

ized within a comparatively short period by the results of scientific research in this field.

Summarizing the known facts, we may say that the form and strength of magnetic fields are controlled: first, by the form, size and quality of the material composing the magnetic circuit; second, by the ampère-turns of the exciting current; third, by the distance between the poles; and fourth, by the shape of pole-pieces. The present paper has to do with the last two factors, pole-distance and pole-form, only; but in order that the experiments here reported may be clearly understood, the apparatus and methods employed will be first described.

I. Apparatus and Methods.

1. *The Magnetic Circuit.*

The general arrangement of the magnetic circuit and its connections is shown in Fig. 1, in which M is the magnet employed in testing the minerals; R, the resistance in series with the magnet M; W, the four wires connecting with the main switch-board; R-S, the switch that reverses the current in M; T, the test-coil used in determining the amount of magnetization in M; G, the galvanometer used to determine the current in T; and B, a switch to make and break the current in M.

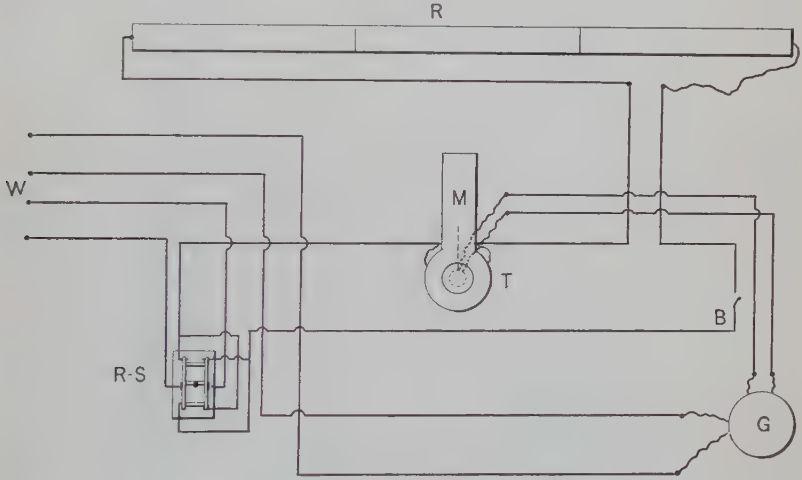
2. *Apparatus Employed in the Traction-Method.*

Fig. 2 shows front- and side-elevations of the apparatus employed in the method (presently to be described) of testing by traction. M is the magnet, with adjustable upper core C; K, the support, attached to the wall above; N, the weighing-device (comprising the spring Z, suspended from K by the wire W, and carrying the support O for the scale-pan O′; and also F, the graduated scale attached to K, and I, the indicator, attached to W); L, L′ and L″, the wires used for adjusting the point of support of the scale-pan O′, or the wire W, into the line of the axis of the core C (L and L′ moving the wire W back and forth respectively in a line perpendicular to the wall X, while L″ moves it parallel to X); M′, the switch-board; R-S, the reversing-switch; G, the galvanometer; T-C, the search-coil; S, the make-and-break switch; Q, the graduated scale, and A, the reel attached, through K, to the scale-pan O′, and serving to measure the pull of the magnet upon the ore.

The magnet, specially made for these experiments, consisted (see M, in the side elevation) of a U-shaped mass of soft-iron, rectangular in section, through the extremities of which were openings, turned to fit large cylinders of similar material, which serve to complete the circuit. The lower cylinder (C′) was set firmly into the U-shaped frame, which was shrunk upon it; the upper cylinder was made to fit closely in the arm which supports it, yet sufficiently loose to allow adjustment, within a range which allows the ends of the cylinders to be brought together or separated ten inches.

Those portions of the cylindrical circuit enclosed between

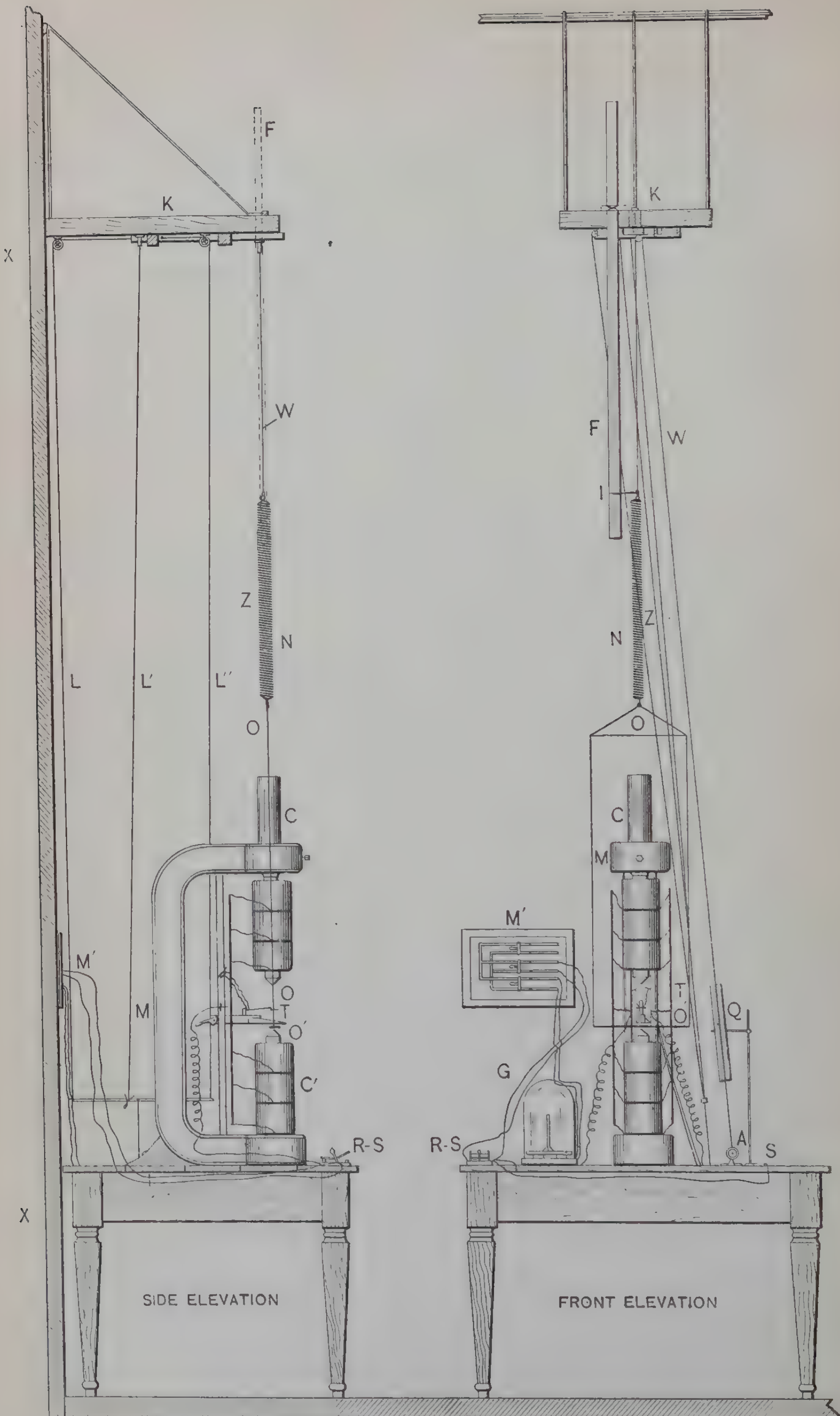
FIG. 1.



General Arrangement of the Magnetic Circuit.

the arms of the U-shaped frame were nearly as large in cross-section as the frame. The extremities of the arms were enlarged to receive the cylindrical circuit, the object being to maintain the same size of circuit throughout its entire length, and so not materially reduce the flux. Twelve inches of the cylindrical circuits of each arm were cut down to receive the exciting coils, thus forming the cores of the circuit. The coils were wedged fast to the cores, thus maintaining their relative position to the magnet, regardless of *its* position. The coils thus faced one another, enclosing the same axis, and, with the cores, could be brought together as the pole-pieces, giving a maximum concentration and a minimum leakage.

Fig. 2.



Apparatus Employed in the Traction-Method.

In the design of the magnet proper, the rules of the latest dynamo-construction were followed, except that the length of the circuit, which was necessitated by the required adjustment, is a radical departure from the latest design. The nature of the work required an adjustment of from 0.5 to 10 in.

a. The Coils.—As shown in Fig. 2, six coils were arranged in two groups—three on either pole. The coils were connected in multiple—primarily, to give maximum flux; secondarily, to facilitate the control of excitation by introducing or throwing out coils, as found desirable. The coils were of high resistance, allowing a current of only 3.5 ampères to pass on a 118-volt circuit. They were, however, wound to resist high temperatures, and would run continuously for several hours without overheating. Each coil was wound with 6500 turns of No. 24 B. & S. wire, giving, for the six coils, 39,000 turns, which, at 3.5 ampères, gives 136,500 ampère-turns of excitation.

b. The Pole-Pieces.—Tests were made with a large number of combinations of pole-pieces of different forms. Four sets of twos, with three odd ones, give twenty-odd possible combinations. The forms used were as follows: (1) Cones with rounded points, with semi-angle of 45°; (2) the same, with semi-angle of 52.5°; (3) cones with circular chisel-edges, the inner side being perpendicular and the outer side forming an angle of 60° with the base; (4) poles with a flat surface tangent to the outer curved edge; (5) poles with a spherical surface of 1.5 in. radius; (6) cones with a semi-angle of 60°, tipped with an inch-cylinder, which in turn is finished off with a spherical surface of 0.5 in. radius; (7) a concave, spherical surface of 4 in. radius, the inner surface being tangent to the outer curved edge.

3. *Methods of Testing Fields Produced by Different Pole-Pieces.*

The fields produced by differently formed pole-pieces of different forms were tested in two ways: first, by means of a search-coil; second, by a new application (as we believe) of an old principle, namely, the use of iron filings in a glass tube. By this method, both vertical and horizontal fields can be tested with equal facility, and both the arrangement and intensity of the lines of force in the field can be determined with great accuracy.

c. Testing with a Search-Coil.—The fields produced by all the forms of pole-pieces used were symmetrical with respect to the central axis of the cores. Tests made, therefore, from the center outward in a radial direction would be duplicated for any other radius which might be taken. The only possible point where the field might vary was on the side opposite the frame; but tests at that point did not show any appreciable change in intensity. We may therefore consider the field as uniform from the center outwards, radially.

The search-coil used in testing the fields was the same as that used in the tractive method, to be described later. It consisted of 100 turns of very fine, insulated copper wire, wound with a rectangular cross-section so closely as to occupy little space, and finally dipped in glue, to make it retain its shape, and also to protect it. The inside diameter was 0.5 in., the same as that of the pan in the tractive method, making the area enclosed by the coil 1.2664 sq. cm.

To facilitate the work of testing, the magnet was set so that the axis of the pole-pieces was vertical. The search-coil was first passed just above the top of the lower pole-piece, starting with the coil encircling the axis, then proceeding laterally, so that the search-coil should occupy, successively, positions distant by 0.5, 1, 1.5, 2, 2.5 and 3 inches from the starting-point. The coil was then passed through the field a second time, but this time equidistant from both poles, and tests were recorded at points located, as in the first series.

In Table I., giving the results of these tests (see p. 422), the first series is designated by A; the second by B. C is employed for a third series, made with the coil passing just below the upper pole-piece.

d. Testing with Iron-Filings and Glass Tube.—A glass tube 0.25 or 0.5 in. in diameter, containing a quantity of iron or steel filings (readily determined by experiment) proportional to the diameter of the tube, closed at the ends, and introduced into a magnetic field, is a useful means of determining the strength and direction of the field. The filings arrange themselves in small columns, which are close together or at some distance apart, according to the intensity of the field. To insure the perfect arrangement of the columns, the tube should be both turned and drawn back and forth in the field.

In measuring the intensity of the field the smaller tube does

fully as well as the larger, and has the additional advantage that it can be set in the groove of an architect's or draughtsman's scale, and, by slipping one upon the other, exact measurements of the field can be taken. The large tube serves best for determining the angle of divergence in weaker fields, the columns of filings rolling end-over-end in the tube, as it is moved across the diverging fields, as along the side of a magnet.

4. *General Forms of Pole-Pieces.*

The various forms of pole-pieces already mentioned may be classed as flat, conical, spherical (concave or convex) and chisel-shaped. These are the four most common forms; and the fields produced by them should be characteristic.

*e. Flat Poles** (Fig. 31).—These pole-pieces were made flat for the full width of the core, the flat surface being tangent to the rounded edge. By rounding off the edge and making it tangent to the face, it was believed that the concentration of the lines of force would be rendered smaller than with square edge, thus producing a more uniform field on the face. This condition was realized to a certain extent; but on examining the fields produced by these flat poles used together, and also combined with different forms, marked variations in density of field will be seen to occur. The flat poles are useful, when combined with pointed poles, in producing fields of great divergence; but the divergence is rather slight at the point, for distances varying from 2 to 6 and 8 in. On bringing the poles closer together, the divergence increases at the point; but the poles have to be brought closer together than is necessary with several other combinations to produce the same divergence.

f. Conical Poles† (Figs. 3 and 11).—Cones with semi-angles of 45° and 52½° were chosen to give maximum concentration, and are found, on trial, to give not only maximum concentration, but maximum divergence from apex to cone. The cone with semi-angle of 45° gave maximum concentration; and poles of this form were used in the traction-method.

g. Spherical Poles (Figs. 19 and 28).—A concave pole-piece

* See Poggendorff's *Annalen*, vol. lxxiv., p. 465; vol. lxxx., p. 497 (1850); vol. xc., p. 248 (1853); vol. cv., p. 49 (1858). Also, *The Electromagnet and Electromagnetic Mechanism*, by S. Thompson.

† J. A. Ewing, *Magnetic Induction in Iron and Other Metals*, New York, 1892, p. 141.

with 4 in. radius of curvature, and corners rounded and tangent to inner surface, was tested with all other forms. The result, in all cases, was a massing of the lines at the edges, leaving the concavity practically void of flux. The convex-spherical surfaces produce fields much resembling those of the conical forms, but exhibiting less concentration.

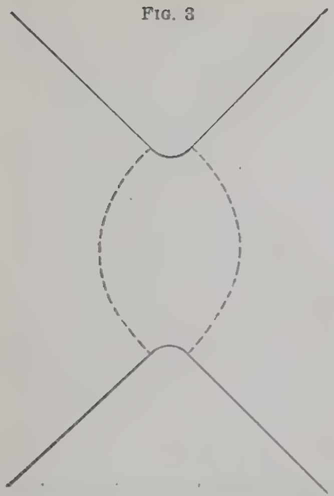
h. Chisel-Edged (*Chamfered*) *Poles* (Fig. 7).—Only one form of chisel-edge pole-piece was tested. It consisted of a cone of 60° semi-angle, with an inch hole drilled in the center. The chisel-edge was thus 60° on the outside and 90° on the inside, and of circular form, in the use of which the field is symmetrical and suffers no distortion due to points and corners. When this form was combined with conical and spherical pole-pieces, strong fields were produced, decreasing from the center outward; when it was combined with flat and concave surfaces, the result was a varying field, which increased in intensity from the center to a line connecting the circular edges above and below, then fell off to a minimum in the outside field.

II. Magnetic Fields.

The fields produced by the different forms of pole-pieces described above may be classed as uniform, ellipsoidal, and conical or conoidal. Fields wholly or in part uniform are rare, even under the most favorable conditions. Fields No. 29 and 30, that portion of No. 30 included between the broken lines, that portion of No. 31 included between the broken lines, and a small portion of the middle part of the ellipsoidal fields (the width depending on pole-distance) give fairly uniform results.

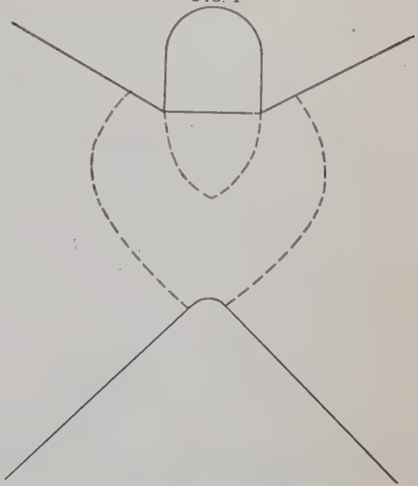
Ellipsoidal fields may be divided into four classes, according to the shape of the pole-pieces forming them, as (1) those which are symmetrical with respect to a plane perpendicular to the axis at the middle point (illustrated by Figs. 3, 11 and 16); (2) those which are unsymmetrical with respect to such a plane, one end of the field being wider than the other (illustrated by Figs. 8, 9, 10, 12, 13 and 14, of which 8, 9 and 10 might well be placed in the preceding class, as they show there is but slight difference between the unsymmetrical ends); (3) annular fields (of which there is but one example, namely, Fig. 7); (4) cupped fields (illustrated by Figs. 4, 5, 6 and 15), in which the whole field is strongly magnetic, but portions are so extremely dense as to give the appearance shown in the diagrams.

FIG. 3



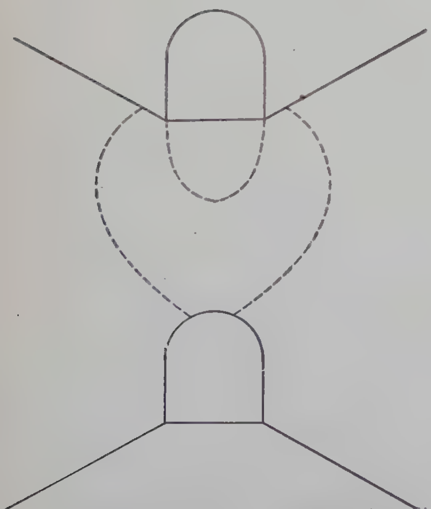
Set of Cones with Rounded Points, Semi-angle 45°. Pole-distance, 2 in.

FIG. 4



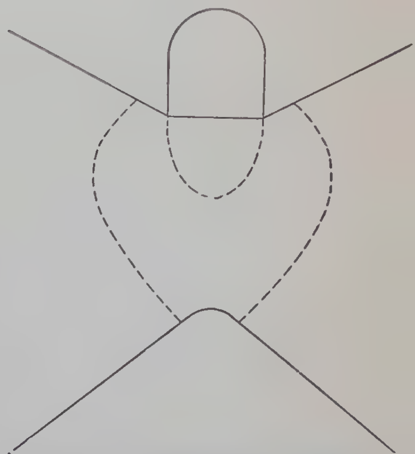
Combination of Circular Chisel-Edged Poles and Conical Pole of Semi-angle 45°. Pole-distance, 2 in.

FIG. 5



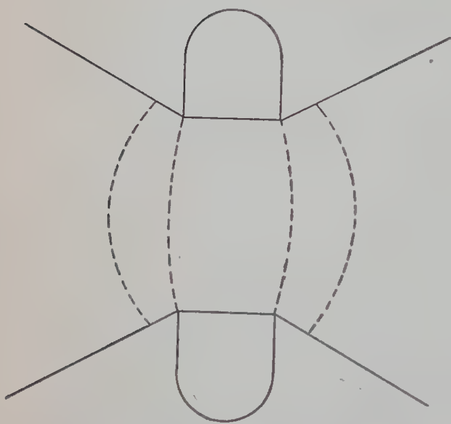
Combination of Circular Chisel-Edged Pole and Spherical Pole of Half-inch Radius. Pole-distance, 2 in.

FIG. 6



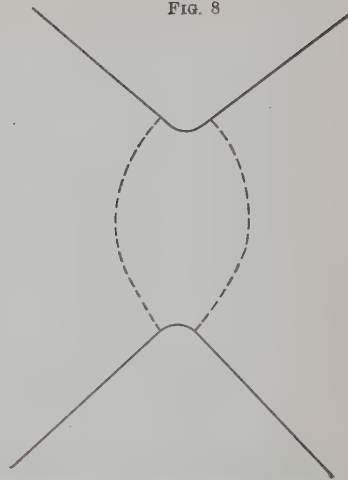
Combination of Circular Chisel-Edged Pole and Conical Pole of Semi-angle 52.5°. Pole-distance, 2 in.

Fig. 7



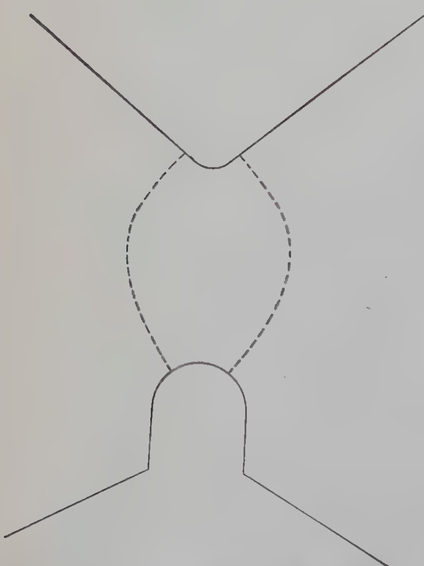
Set of Circular Chisel-Edged Poles. Pole-distance, 2 in.

Fig. 8



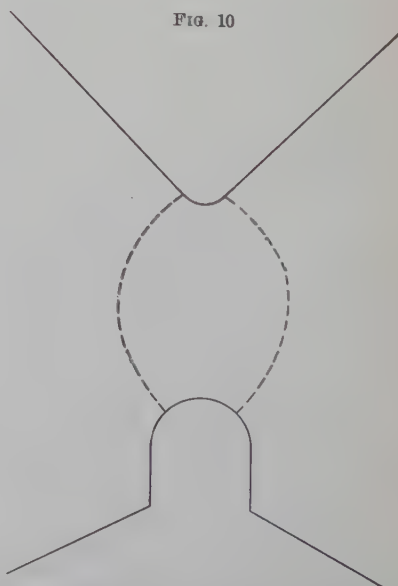
Combination of Two Conical Poles, of Semi-angle 52.5° and 45° Respectively. Pole-distance, 2 in.

Fig. 9



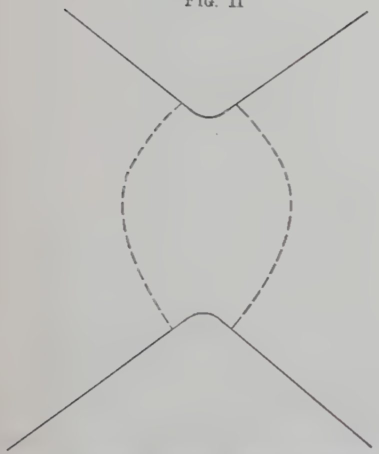
Combination of a Conical Pole of Semi-angle 52.5° and a Half-inch Spherical Pole. Pole-distance, 2 in.

Fig. 10



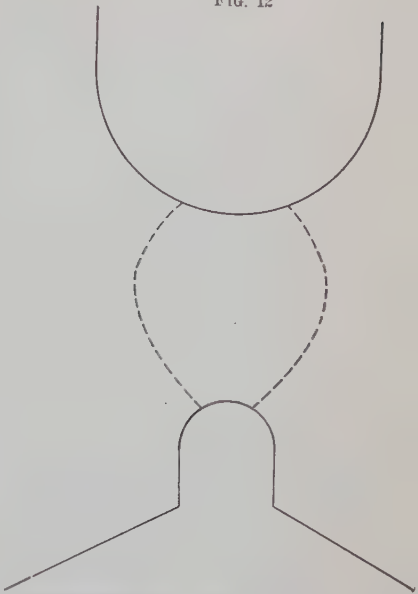
Combination of a Conical Pole of Semi-angle 45° and a Half-inch Spherical Pole. Pole-distance, 2 in.

FIG. 11



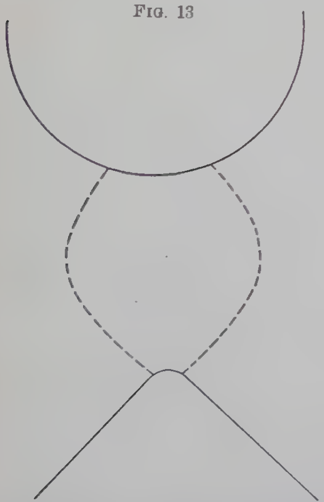
Set of Conical Poles with Rounded Points of Semi-angle of 52.5°. Pole-distance, 2 in.

FIG. 12



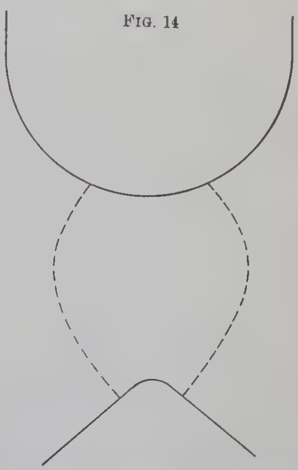
Combination of Two Spherical Poles with Radius of 1.5 and 0.5-in. Respectively. Pole-distance, 2 in.

FIG. 13



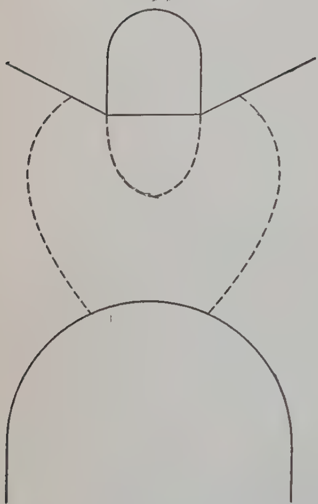
Combination of a Spherical Pole of 1.5-in. Radius and a Conical Pole with Rounded Point of Semi-angle 45°. Pole-distance, 2 in.

FIG. 14



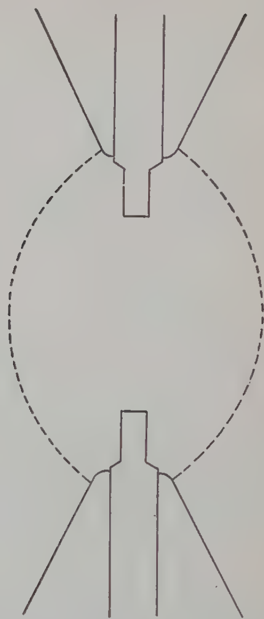
Combination of a Spherical Pole of 1.5-in. Radius and a Conical Pole of Semi-angle 52.5°. Pole-distance, 2 in.

FIG. 15



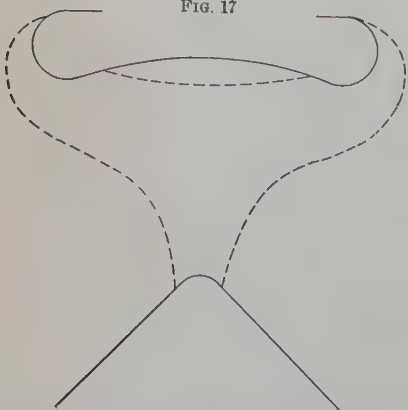
Combination of a Circular Chisel-Edged Pole and a Spherical Pole of 1.5-in. Radius. Pole-distance, 2 in.

FIG. 16



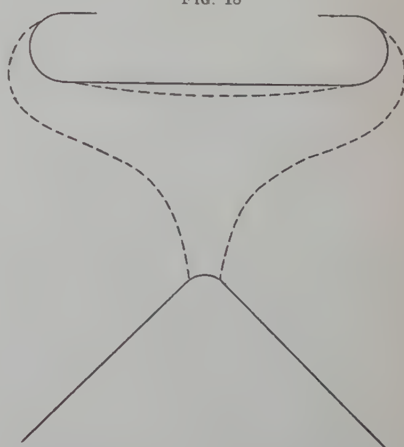
Set of Conical Pole-Pieces, Fitted with Adjustable Plugs, as Used in the Rod-Method of Testing. Pole-distance, 2 in.

FIG. 17



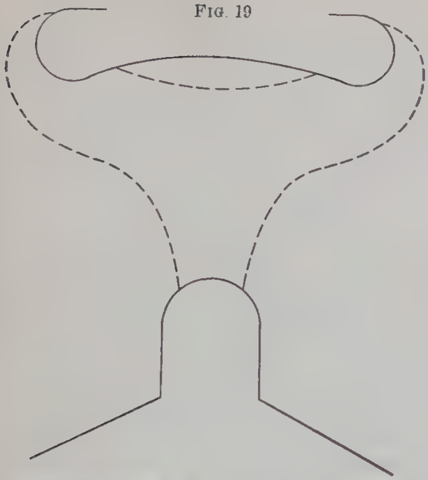
Combination of a Concave Pole (4-in. Radius of Curvature) with a Conical Pole (Semi-angle 45°). Pole-distance, 2 in.

FIG. 18



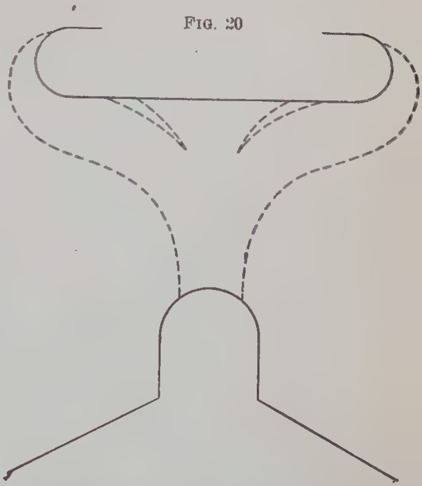
Combination of a Flat Pole (1.5-in. Radius) and a Conical Pole (Semi-angle 45°). Pole-distance, 2 in.

Fig. 19



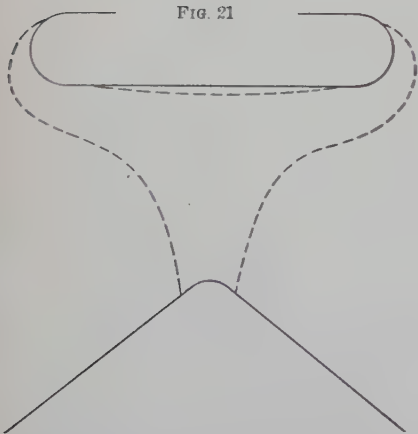
Combination of a Concave Pole-Piece (4-in. Radius of Curvature) and a Spherical Pole (0.5-in. Radius). Pole-distance, 2 in.

Fig. 20



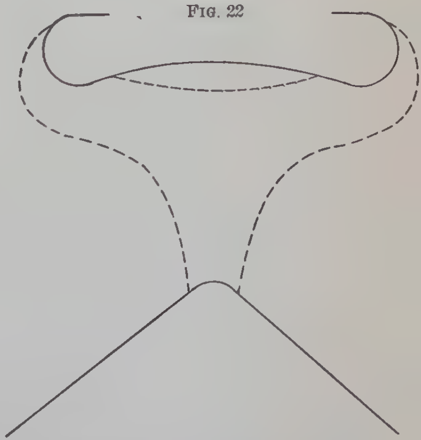
Combination of a Flat Pole (1.5-in. Radius) and a Spherical Pole (0.5-in. Radius). Pole-distance, 2 in.

Fig. 21



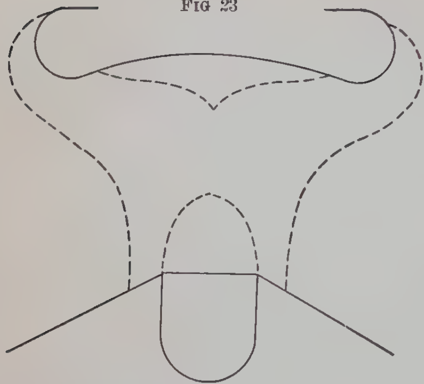
Combination of a Flat Pole (1.5-in. Radius) and a Conical Pole (Semi-angle 52.5°). Pole-distance, 2 in.

Fig. 22



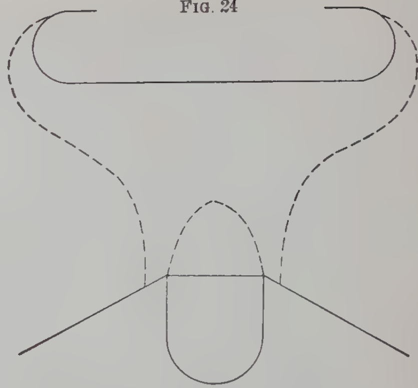
Combination of a Concave Pole-Piece (4-in. Radius of Curvature) and a Conical Pole (Semi-angle 52.5°). Pole-distance, 2 in.

FIG. 23



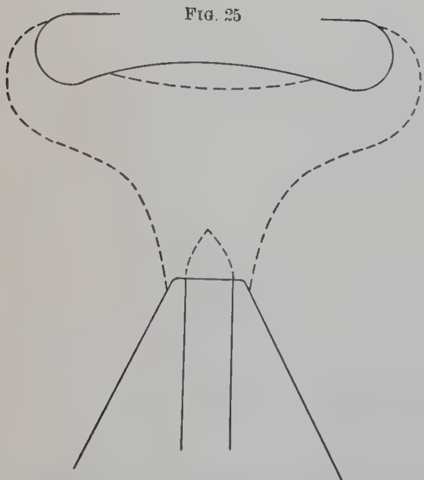
Combination of a Concave Pole-Piece (4-in. Radius of Curvature) and a Circular Chisel-Edged Pole. Pole-distance, 2 in.

FIG. 24



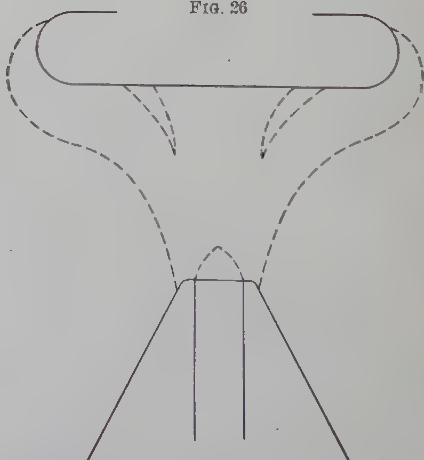
Combination of a Flat Pole-Piece (1.5-in. Radius) and a Circular Chisel-Edged Pole-Piece. Pole-distance, 2 in.

FIG. 25



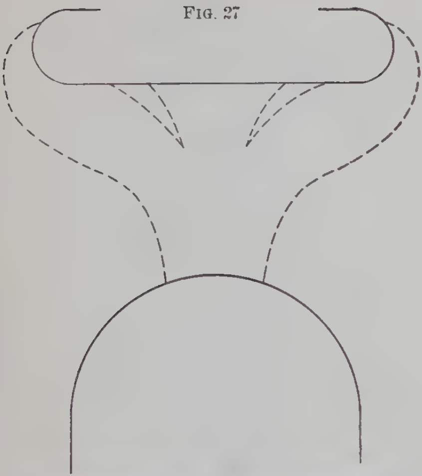
Combination of a Concave Pole-Piece (4-in. Radius of Curvature) and a Hollow Pole-Piece, as Used in the Rod-Method. Pole-distance, 2 in.

FIG. 26



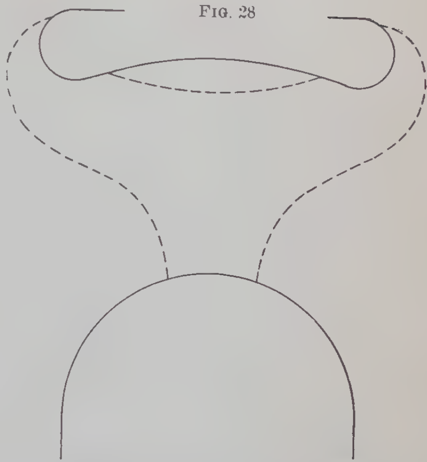
Combination of a Flat Pole-Piece (1.5-in. Radius) and a Hole Pole, as Used in the Rod-Method. Pole-distance, 2 in.

FIG. 27



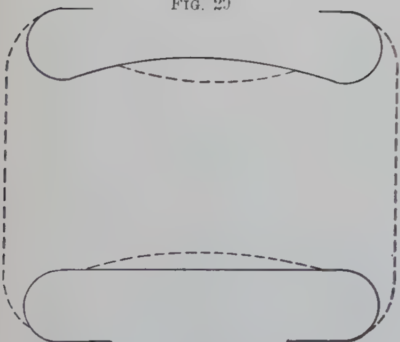
Combination of a Flat Pole-Piece (1.5-in. Radius) with a Spherical Pole (1.5-in. Radius). Pole-distance, 2 in.

FIG. 28



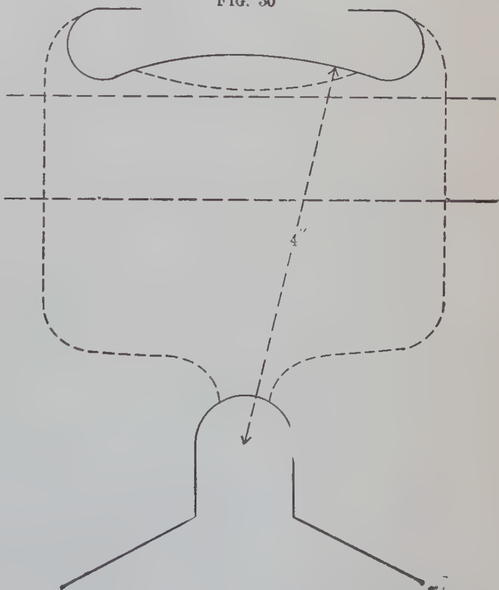
Combination of a Concave Pole-Piece (4-in Radius of Curvature) and a Spherical Pole (1.5-in. Radius). Pole-distance, 2 in.

FIG. 29



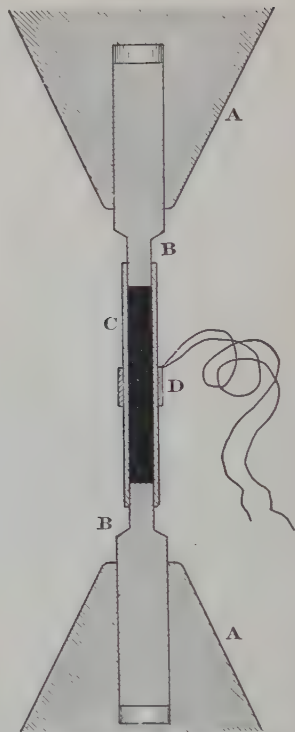
Combination of a Concave Pole-Piece (4-in Radius of Curvature) and a Flat Pole (1.5-in. Radius). Pole-distance, 2 in.

FIG. 30



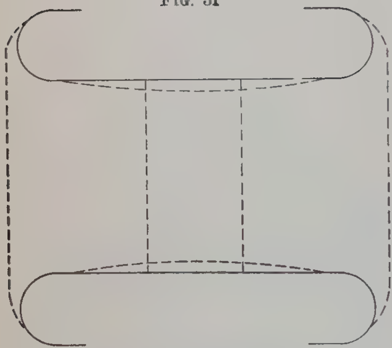
Combination of a Concave Pole-Piece (4-in. Radius of Curvature) and a Spherical Pole (0.5-in. Radius; the Center of the Spherical Surface of the Lower Pole being the Center of the Curvature of the Concave Pole).

FIG. 32



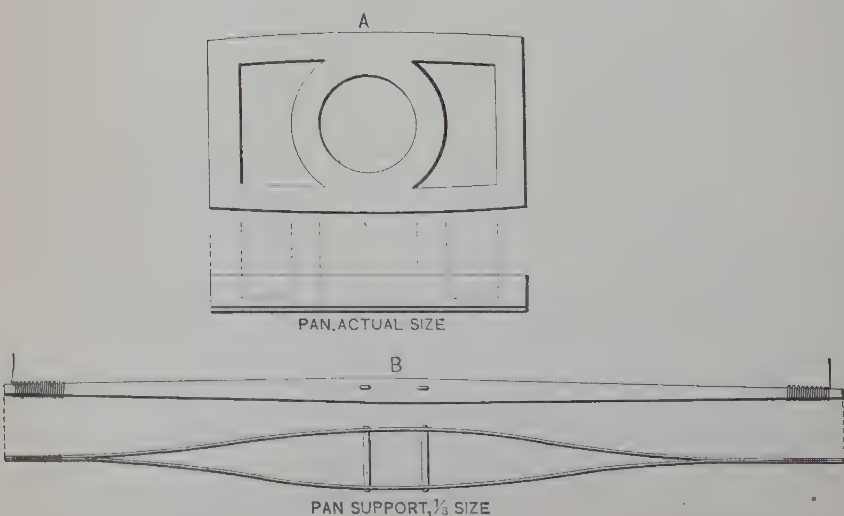
Apparatus for Glass-Tube Method. A, pole-pieces; B, adjustable plugs; C, glass tube; D, test-coil.

FIG. 31



Set of Flat Poles (1.5-in. Radius).

FIG. 33.



Details of Pan and Support.

Conical fields are almost as rare as uniform fields. They merge into the conoidal shape so quickly that only small portions of any field can be said to be conical. However, the lower portions in Figs. 17, 18, 19, 20, 21, 22, 27 and 28 may be considered as conical.

Only one form of conoidal field was obtained, namely, the "ogee," which may be classed as cupped, solid, or ringed.

The cupped fields are due to projecting portions of pole-pieces, which tend to concentrate the lines of force. Here, as in the cupped ellipsoidal fields mentioned above, the great differences in density of field are accountable for the marked contrast between the different portions of the fields. Figs. 17, 18, 19, 21, 22, 23, 25, 28, 29, 30 and 31 are illustrations.

As to the solid ogee conoidal fields, it must be said that no arrangement of pole-pieces was found, producing conical and conoidal fields, which would give uniform results all the way across the upper pole-face, except that of Fig. 24, which gave a slight decrease from the center outward, but was cupped below. Figs. 18, 21 and 31 came nearest to being uniform, but, as the diagrams show, were less dense in the center.

In the ringed fields the central and outer portions are dense, while an annular space between is much less dense. This is best shown in Figs. 20, 26 and 27.

Table I. gives the results of search-coil tests on the fields described above. As already observed (see p. 410 above), there are two series of tests, here recorded as A and B; those of B having been made midway between the poles—the total pole-distance being the same for both A and B. The first column of the table refers to the figures which show the forms of the poles, etc., and in these figures the dotted lines give the results of the filing-tests. Table and diagrams, taken together, thus represent all the tests.

The combinations with pole-pieces shown in Figs. 16, 25 and 26, which were employed in the rod-method, and are described below under that title, were not intended to be used in the investigations on field-form and strength, but were tested nevertheless, and the results are given in the table.

5. *Methods of Testing for Magnetic Permeability.*

Two methods were employed in these tests: the rod-method and the traction-method.

TABLE I.—*Number of Lines of Force in Each* 1.2664 *Sq. Cm. of Field, at Successive Distances from the Center.*

Figs.		Distances from the Center, in Inches.						
		0.	0.5.	1.	1.5.	2.	2.5.	3.
3	A	8708.975	3751.559	2411.716	1751.794	1339.842	937.888	669.910
	B	2676.497	2411.716	1885.779	1504.623	1179.061	913.092	643.124
4	A	8708.975	4019.527	2465.310	1885.779	1339.842	913.092	643.124
	B	2576.497	2411.716	2050.560	1617.811	1179.061	913.092	643.124
5	A	9218.111	4702.651	2280.935	1617.811	1133.655	913.093	643.124
	B	2679.685	2411.716	2050.560	1347.029	1125.467	913.093	643.124
6	A	8574.992	4019.527	2679.685	2143.748	1504.623	1071.874	803.905
	B	3112.434	2679.685	2197.341	1779.592	1339.842	913.092	643.124
7	A	3215.662	4585.464	3483.590	2411.716	1504.623	1071.874	697.718
	B	2947.652	2947.652	2518.903	1939.373	1617.811	1071.874	697.718
8	A	8950.147	3590.777	2411.716	1724.998	1339.842	913.092	643.124
	B	2518.903	2411.716	2050.560	1347.029	1179.061	913.092	643.124
9	A	7664.899	4585.464	2143.748	1617.811	1179.061	913.092	643.124
	B	2518.903	2305.529	1939.373	1617.811	1179.061	913.092	643.124
10	A	8307.023	3858.746	1885.779	1347.029	1071.874	803.905	643.124
	B	2411.716	1885.779	1724.998	1339.842	1071.874	697.718	643.124
11	A	8092.648	4019.527	2518 903	1885.779	1339.842	913.092	643.124
	B	2518.903	2250.935	1885.779	1617.811	1339.842	913.092	643 124
12	A	8682.179	4126.714	2197.341	1617.811	1179.061	913.092	643.124
	B	2679.685	2250.935	1885.779	1347.029	1071.874	913.092	643.124
13	A	4126.714	3751.559	2411.716	1724.998	1339.842	913.092	643.124
	B	2679.685	2250.935	2050.560	1617.811	1071.874	803.905	535.937
14	A	7771.086	3858.746	2411.716	1885.779	1339.842	913.092	643.124
	B	2733.278	2465.310	1885.779	1347.029	1133.655	913 092	643.124
15	A	5466.564	4434.682	3112.434	1939.373	1179.061	913.092	643.124
	B	3001.247	2679.685	2250.935	1724.998	1339.842	913.092	643.124
16	A	10718.740*	2250.935	1347.029	968.686	803.905	643.124	535.937
	B	1347.029	1339.842	1179.061	913.092	913.092	589.530	589.530
17	A	7245.149	4126.714	2411.716	2143.748	1347.029	1071.874	803.905
	B	3215.622	2947.652	2679.685	2305.529	1724.995	1179.061	803.905
18	A	7503.118	4434.683	2786.872	2143.748	1617.811	1179.061	803.905
	B	3590.777	3483.590	2947.652	2518.903	1885.779	1339.842	913.092
19	A	8574 992	5627.345	2679.685	2050.560	1617.811	1179.061	803.905
	B	3483.590	3215.622	2733.278	2250.935	1779.592	1133.655	857.499
20	A	6270.462	4823.433	2576.497	1779 592	1339.842	1179.061	803.905
	B	2947.652	2786.872	2679.685	2250.935	1885.779	1179.061	803.905
21	A	7503.118	5091.401	3322.809	2411.716	1724.998	1179.061	803.905
	B	3483.590	3322.809	2947.652	2518.903	2050.560	1347.029	1071.874
22	A	7084.368	4702.651	3215.622	2411.716	1671.404	1179.061	913.092
	B	3377.403	3215.622	2947.652	2679.685	2143.748	1347.029	1071.874
23	A	4327.496	4702.651	4126.714	3001.274	2050.560	1393.436	913.092
	B	3751.559	3590.777	3377.403	2841.466	2143.748	1393.436	913.092
24	A	4585.464	5680.939	4126.714	3215.622	2143.748	1347.029	1071.874
	B	8574.992	4126.714	3751.559	3112.434	2197.341	1617.811	1071.874
25	A	7610.305	6163.275	2054.840	2143.748	1617.811	1071.874	803.905
	B	3483.590	3322.809	3001 247	2518.903	1885.779	1339.842	913.095
26	A	7664.899	6538.431	2841.466	2197.341	1617.811	1179.061	1179.051
	B	3751.559	3483.590	2054.840	2518.903	1885.779	1179.061	803.905
27	A	6431.244	5466.564	4019.527	2518.903	1724.998	1179.061	913.092
	B	3858.746	3590.777	3215.622	2576.497	1885.779	1347.029	913.092
28	A	6699.252	5895.307	4019.527	2679.685	1724.998	1133 655	913.092
	B	3751.559	3590.777	3215.622	2679.685	2143.748	1724.998	913.092

* Plug tip enclosed by coil.

TABLE I.—*Continued.*

Figs.		Distances from the Center, in Inches.						
		0.	0.5.	1.	1.5.	2.	2.5.	3.
29	A.......	4019.527	4019.527	4327.496	4702.651	2143.748	1179.061	803.905
	B........	3537.184	3215.622	3590.777	3215.622	2518.903	1939.373	1347.029
30	A	6977.181	3590.777	1939.373	1617.811	913.092	535.937	375.155
	B........	1885.779	1724.998	1671.404	1347.029	1071.874	803.905	535.937
	C*......	1939.373	1939.373	2250.935	3322.809	1885.779	913.902	697.718
31	A.......	4019.527	4019.527	4126.714	5091.401	2411.716	1339.842	913.092
	B........	3751.559	3751.559	3590.677	3112.434	2143.748	1347.029	913.092

i. The Rod-Method.—This is a modification of a method frequently used in the laboratory to determine the magnetic permeability of iron and steel rods. As described by Ewing,† it consists in placing an exciting coil and a search-coil, side by side, on a long rod of the material to be tested. By suddenly jerking off the search-coil, and removing it to a distance such that the induction is reduced to zero, the flux passing through the rod can be determined. The quantity B (the degree of magnetization in the material) could thus be determined. By repeating the operation as before, with the exception that the test-rod is replaced by a glass tube or wooden rod, H (the degree of magnetization in air) can be determined. The ratio of the flux in the rod to the flux in air will give the permeability μ of the rod.

This method, however, is not exact, for, first, the rod would have to be very long to insure a uniform field in which to place the search-coil; secondly, the replacing of the test-rod by glass or wood would so affect the field that H could not be determined with accuracy; and thirdly, the resistance of the return-circuit for the flux would be infinitely great, whereas it should be infinitely small, in order that as many lines of force as possible would be forced through the test-piece.

Another difficulty, preventing the application of this method, was that long rods of metal, and especially of pure minerals, could not be obtained.

* A third series of tests, made by passing the coil just below the upper pole-piece.

† *Magnetic Induction in Iron and Other Metals*, p. 65.

The following method, which somewhat resembles Ewing's Isthmus Method,* was therefore adopted.

j. Method Employed in These Experiments.—Pole-pieces, conical in form, with semi-angle of approximately 45°, were turned to fit the cores of the magnet already described. A half-inch hole was drilled and reamed through the central part of the cone nearly to the base. Soft iron plugs were turned to fit the holes, and of a size to allow adjustment. One end of each plug was turned down for a distance of 0.5 in. to 0.25 in. diameter. The exact form and dimensions of these pole-pieces and plugs can be seen in Fig. 32.

A glass tube of 0.25 in. inside diameter, encircled at the middle by a search-coil, could be placed between the two adjustable pole-pieces, which were separated by several inches, and the smaller ends of the same could be inserted in the ends of the glass tube. The tube was graduated and marked at two extreme points (2 in. apart), which served to indicate the amount of material as compared with the standard 2-in. metal rods tested.

Search-coils of two sizes, one having 100 and the other 500 turns of wire of the same size, were used: the coil of fewest turns in testing the more highly magnetic, and the other for the more feebly magnetic substances. The deflection of the galvanometer is increased and the possibility of errors in reading is reduced by the use of the larger coil.

The material to be tested is placed in the glass tube. From time to time, while the tube is being filled, the pole-pieces (the plugs) are introduced, and the current is turned on. In this way the material is compressed until when it reaches the upper mark no further compression is possible with the plugs under the force acting. With rods this is, of course, unnecessary. When properly filled, the ends of the plugs are adjusted to occupy positions equidistant from the apexes of the conical pole-pieces. The coil is also adjusted so as to be midway of the material to be tested in the tube.

By reversing the current, the flux through the magnet is re-

* "The Isthmus Method." *Magnetic Induction in Iron and Other Metals*, by J. A. Ewing, p. 132. "On the Magnetization of Iron and Other Metals in Very Strong Fields," *Philos. Trans. Roy. Soc. of London*, Vol. clxxx. (1890), p. 221, J. A. Ewing and Wm. Low.

duced from a maximum to zero. One-half of the throw is then taken as a measure of the flux.*

B can be determined, and H also, by introducing a small piece of wood to keep the plugs at the proper distance apart.

This method has all the advantages of the rod-method, and none of its disadvantages. If solid rods of pure mineral could be obtained, they could be tested in the same manner. But such rods can be obtained for a few minerals only, and for this reason, as well as to save time and cost, crushed material was used in the tests.

k. Difference in the Results of the Two Methods.—By reason of the large proportion of air-space existing between the particles, when crushed material is tested, the quantity obtained from the ratio $\frac{B}{H}$ is not the true permeability. In cast-iron, for example, the crushed product, unsized below 190-mesh, gives only 33.79 per cent. of the permeability obtained for a rod of the same material. In other words, there is a fall of 66.21 per cent. from the actual permeability, as appears from the following tests made on a number of metallic iron compounds:

TABLE II.—*Comparative Tests of Filings and Solid Rods.*

	Value of μ.	Percentage of Rod-Test.
1. Wrought iron, rod,	7.177	
Wrought iron, filings,	2.387	33.25
2. Steel casting, rod,	7.016	
Steel casting, filings,	2.419	34.47
3. Tool steel, rod,	6.612	
Tool steel, filings,	2.338	35.36
4. Cast-iron, rod,	6.120	
Cast-iron, filings,	1.889	30.80
Average percentage of rod-test,		33.47

The attempt to find whether this variation would be the same for other metals failed, because the method was not delicate enough. The following metals were tested in comparison with filings of them without noting any difference of flux. The flux was in all cases the same as that of air, that is to say, aluminum, carbon, cadmium, copper, lead, magnesium, tin and zinc,

* This was possible, by reason of the softness of the metal composing the metallic circuit.

when tested in rods, showed a permeability of 1. Of the minerals tested in the form of powder, only three gave any results, namely, franklinite (1.482), ilmenite (1.241) and pyrrhotite (1.068).

Rods of these minerals not being obtainable for testing, no data as to their permeability in that form could be secured. We do not know, therefore, whether there is any change in the permeability as a result of the reduction of size. It is, however, permissible to assume that there is probably a falling-off, due to the introduction of air into the mass, especially for highly magnetic substances; but that for the less magnetic substances, which differ but little from air, the fall in permeability would be slight. Of those having less permeability than air, the permeability may rise to nearly that of air. How great the variation is it is hard to say; hence no correction of observations can be made, and only comparative results can be obtained, with crushed cast-iron as a basis.

The comparison of ores with cast-iron is based primarily on the fact that cast-iron can be crushed and sized like minerals. Yet such a comparison is faulty because, cast-iron being tougher than most ores, the grains produced by crushing it are more rounded in form than the irregular grains of ores reduced by the same process. Filings can scarcely be used for comparison, being still more angular in form, or shaped like shavings.

In calculating B and H, a correction* must be made for the flux in the glass tube, and also in the coil itself. If the search-coils be wound close and the insulation be very thin, with coils of fine wire and of few turns, this correction is practically negligible. This would be the case with the 100-turn coil, as regards the flux included between the inside and outside; but for the 500-turn coil a correction must be made. The correction for induction through the glass tube is necessary in both cases. These corrections can be made by employing the following formulas:

$$(1) \qquad B = \frac{F - (A - A')H}{A};$$

F being the total flux enclosed by the coil; A, the cross-section of material (test-sample or air) treated; and A′ the cross-sectional area of glass tube and coil.

* J. A. Ewing, *Magnetic Induction in Iron and Other Metals*, p. 66.

$$(2) \qquad H = \frac{F}{A - A'}$$

when the glass tube has the same resistance as air, which is true in this case.

1. The Traction Method.—In the arrangement of the apparatus for this method, the large magnet is set upright on one end as a base; the end with the loose core being uppermost, to allow adjustment (see Fig. 2).

About 6 ft. directly above the magnet was a triangular frame of wood attached to the wall by its base and rods, and provided with a system of levers, operated by cords reaching to the table and within easy reach of the operator, by means of which a pulley on one of the levers could be brought into the axis of the cores. To one end of a small flexible copper wire, passing over this pulley, were attached a pan, spring, etc., to be described later. The other end extended to the table at the right of the magnet's base, and there engaged with the axle of a small windlass. The bearing at this end was formed of curved brass springs, so arranged as to press upon the axle and present considerable frictional resistance to its revolution. A disk at the other end of the axle furnished a means of turning the windlass.

The other end of the wire, hanging over the center of the upper core, was provided with a swivel, to which was fastened a wire, extending to the left, at right-angles to the pendant wire, and ending in a rectangular loop which enclosed a porcelain scale. This loop both prevented the twisting of the wire and served as an indicator.

To the swivel was attached a spring, and to the lower end of the spring a pan, in which was placed the ore, the attraction of which was to be measured.

The four springs were wrapped on a lathe to insure regular spirals, and were made respectively of Nos. 14, 15, 19 and 20 standard-gauge piano-wire. They are designated respectively by the letters A, B, C and D, when referred to in this paper.

Only one of these springs, D, could be calibrated. The others, by reason of slight irregularities in the spirals, refused to give uniform results. In all cases, therefore, the stretch in centimeters was noted, and its equivalent in grammes was found by suspending the spring and attaching a scale-pan, into which

weights were placed until the same stretch was obtained as had been noted in the experiment. This weight, plus the weight of scale-pan and attachment, gave the pull in grammes corresponding to the observed stretch in centimeters.

The calibration for spring D was found to be one gramme for every 0.55 cm. of stretch.

The pan in which the ore was placed* consisted of a piece of vulcanized fiber 0.13 in. in thickness, through which a half-inch hole had been drilled and reamed to exact size. To the bottom of this perforated piece was glued another thin piece of fiber, and the whole was cut to the desired form (Fig. 33). A large part of the fiber was cut away from the upper surface of the pan to give lightness, and to reduce the influence of the mass on the magnetic field and on the materials treated.

Two strips of seasoned hickory $\frac{3}{32}$-in. thick, $\frac{3}{8}$-in. wide at the middle and $\frac{2}{16}$-in. at the ends, and 13 in. long, curved at the edges to resist the strains produced by upward pull, were placed side by side, and the ends were wrapped with linen thread, the edges being slightly notched to give the wrapping a firmer hold. When securely fastened at the ends, the two strips were separated at the middle, and small triangular cross-pieces of similar material were mortised into the side-strips—a flat side up. These cross-pieces were placed an eighth of an inch below the edge of the strips and an inch apart, thus forming a support for the pan. The pan proper had its sides cut to fit in between these side-strips, and, being made a little large, was firmly held when pressed into its seat.

The pan-support was suspended by a small copper wire attached to each end. These suspension-wires were kept parallel for a distance of some three feet by a round cross-bar of hickory, tapering in diameter from $\frac{1}{8}$-in. at the middle to $\frac{3}{32}$-in. at the ends. Above this cross-bar the two wires were united, and attached to the lower end of the detaching-spring described above.

By this arrangement the detaching-spring, and therefore the point at which the power of detaching was applied, were brought directly above the pan—pan and spring lying within the axis of the cores. By adjusting the point of support of the pan, the

* *Poggendorff's Annalen* (Plücker), vol. lxxiv., 1848, p. 321.

pan itself can be made to assume any position perpendicular to the axis of the cores. The arrangement of levers on the frame above, as described, facilitated this adjustment.

The scale, of which the position has already been indicated, was used in measuring the pull of highly magnetic substances, such as iron, steel, etc. Another scale was placed parallel with and very close to the wire leading from the windlass, and supported in place by a standard and clamp. A small, fine wire, attached at right-angles to the windlass wire, moved over the scale as the windlass was turned, thus serving as an indicator.

A wooden standard, wedged between the upper and lower arms and parallel to the bottom or back of the magnet, served as a support for feed-wires, leading to the galvanometer and the search-coil, and also for an adjustable fork-arrangement used in checking the upper movement of the pan-support. The whole apparatus as described, with minor details, is shown in Fig. 2, which will serve to elucidate the above description.

Frames supporting several thousand feet of galvanized-iron wire, in heliacal form, served as resistance.

A double reversing-switch, placed in direct connection with the main circuit, allowed a reversal of the current in the coils, and thus of the magnetization of the magnet. A small make-and-break switch was placed in line with one of the wires leading to the magnet from the reversing-switch, so as to allow the current to be thrown on or off at will without reversing.

A separate circuit connected the galvanometer with the mains, to secure a steady current through the former, which was of the direct-reading d'Arsonval type.

The method of operation is as follows: Conical pole-pieces, with semi-angle of 45°, are employed: first, to obtain maximum concentration; second, for convenience of use with the pan. When the suspension has been so adjusted as to bring the pan directly over the apex of the lower pole-piece, the pan is removed from the holder; the material to be tested is put in, settled, slightly compressed with the rounded end of a test-tube, and then struck off even, and rolled smooth with the side of the test-tube, all particles adhering to the pan being carefully removed. The pan is then placed in its support, which is then raised $\frac{1}{8}$-in. or more above the apex of the cone. When the oscillations of the pan have ceased, it is slowly lowered by means

of the windlass until its bottom just touches the pole-piece, as is shown by the cessation of the slight tremors due to the spring-attachment above.

The current is now turned on, and the full strength of the magnetic field is concentrated upon the material in the pan. Gravity being eliminated, the force necessary to detach the pan will be proportional to the divergence of the lines of force, the flux, susceptibility and mass of material treated, as will be explained further on.

By slowly turning the windlass, the spring is stretched until it overcomes the magnet's attraction; then the pan, with its support, springs upward and is caught on the two prongs of the fork, which extend one on either side of the field. By adjusting the fork so that it is only a fraction of an inch above the pan-support, when the pan is resting on the pole, the material in the pan is but slightly disturbed, or, at least, not spilt—so that the test can be repeated over and over again. It is necessary, however, to replace the contents of the pan, if disturbed in the least, for reasons which will be explained later.

By means of the calibrated spring, D, the centimeters of pull can be at once determined as grammes; but, with the other springs, each measurement of pull will have to be transformed, as previously described.

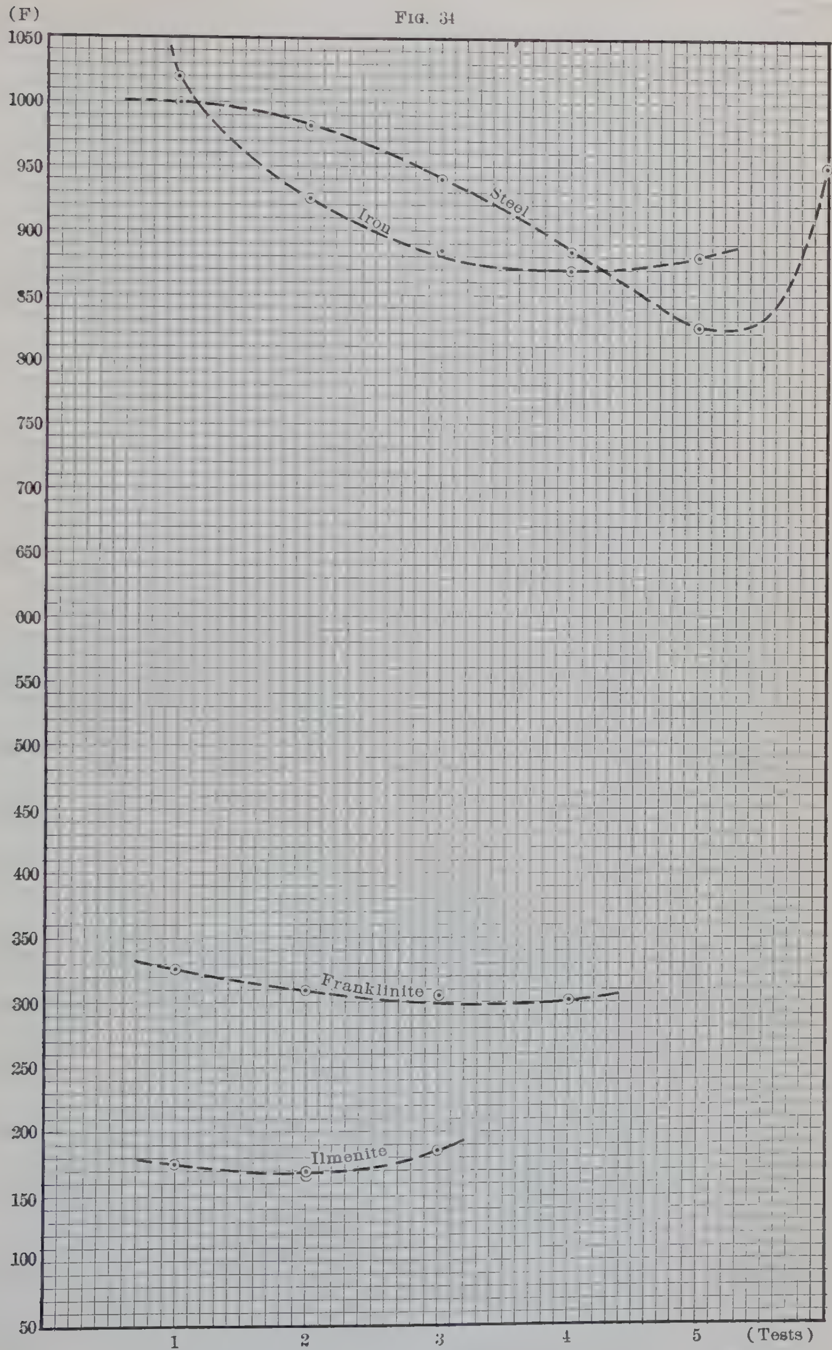
m. Effect of Loosening the Charge.—Several tests were made to determine the effect of loosening the contents of the pan. Consecutive tests, made without replacing and settling the charge, as in the initial test, gave the results shown in the following table:

TABLE III.—*Consecutive Tests, Without Replacement of Charge, Showing Pull in Centimeters of Scale.*

No.	Iron.	Steel.	Franklinite.	Ilmenite.
1,	1018	1000	325	175
2,	925	982	307	170
3,	885	948	305	180
4,	871	885	300	...
5,	880	837	...	...
6,	...	947	...	...

As will be seen from this Table, and the curves in Fig. 34, there is more or less sudden falling-off of the tractive force, but a final rise, most marked in the case of steel. Ilmenite is,

FIG. 34



Curves Showing Variation in Tractive Force (F), Due to the Loosening of the Contents of the Pan, by Successive Tests without Intermediate Replacement. (See Table III.)

however, an exception, a slight rise being noted, with little or no fall.

The above results are the average of a number of tests, some of which gave little variation, others quite marked rises and falls, but all of which followed, in a general way, the variations as indicated above.

From the above it will be seen to be necessary to repack the charge carefully for each test. By so doing, and by careful manipulation of apparatus, results can be made to check with surprising accuracy, as is shown by two series of tests, given below:

TABLE IV.—*Tests Made with Repacking of Charge after Each, Showing Pull in Centimeters of Scale.*

Test No.	Quartz.	Hematite.
1,	600	1.450
2,	600	1.451
3,	601	1.450
4,	600	1.450
5,	600	1.452
6,	601	1.449
7,	601	1.450
8,	599	1.450
9,	602	1.451
10,	600	1.450
Average,	600.4	1.4503

The pan itself was found to be slightly magnetic, but this, being a constant element, introduced no error. It may even be considered as a positive advantage; for with the more feebly paramagnetic and the diamagnetic substances a pull could always be obtained, although often less than that of the empty pan. The difference between the pan-pull and the combined pan-and-mineral pull gave the pull due to the mineral. If this had not been the case, the method would not have been applicable with diamagnetic substances.

n. Corrections.—In the case of the highly magnetic substances, a correction must be made for the stretch of the suspending wires. This was partially obviated by taking the readings from the scale above the magnet. Here the indicator is connected directly with the end of the spring, thus eliminating the stretch of the wire from windlass to spring. There remains to be corrected the stretch of the suspension-wires. No

constant could be determined which might be subtracted for every gramme of pull: but the stretch for each test was determined by noting the change of starting-point—the difference between the two points giving the stretch of wire.

Another correction must be made for the fall of magnetization due to the heating of both coils and core. A series of tests will show this to the best advantage.

TABLE V.—*Showing Decrease of Magnetization Due to the Heating of Coils and Core.*

No. of Test.	Temperature. Deg. Fahr.	Time. Minutes.	Magnetization. (Lines of Force.)
1,	73.	0	11254.677
2,	74.8	10	11093.895
3,	78.25	20	10880.521
4,	82.65	30	10718.740
5,	87.75	40	7935.867
6,	93.40	50	7771.086

The effect of the heating is to increase the resistance of the coils and the reluctance of the magnetic circuit, in both ways reducing the magnetization. Two methods may be employed to obviate this decrease of magnetization, namely, increase the current proportionally or keep the coils and core at constant temperature. As the current was on during a small part only of the time of testing, a constant temperature could easily be maintained. A certain temperature was obtained by allowing the current to pass through the coils for several minutes, and was then kept constant. No correction is necessary, therefore, except with bismuth, which was tested with the magnet cold, which will account for the higher flux noted for the same pole-distance.

6. *Theory.*

The tractive force having been determined, the question arises, How can the permeability be obtained from it? Before this can be done, the quantities which combine to produce the tractive force must be determined. Tests were, therefore, made on: (a) varying weights of mineral, with equal pole-distance and magnetization; (b) varying pole-distances, with equal volumes and magnetization; (c) varying magnetization, with equal volumes and pole-distances; and (d) varying size, all other conditions being constant.

o. Effect of Varying Weight on Tractive Force.—It was found necessary to employ equal volumes, filling the scale-pan each time, to insure equal divergence of the lines of force through the material treated. If equal weights had been taken, the experiments would have been made under different conditions in this respect. With equal weights, and therefore varying volumes, the ratio of air-gaps to the depth of material tested will vary, thus causing a variation in intensity and divergence of field. Again, with equal volumes of mineral, the conditions under which the grains act upon each other and upon the magnetic field will be the same in the different experiments.

The effect of varying weight will be seen in the following table:

TABLE VI.—*Variation in Tractive Force Due to Varying Weight of Mineral, as Shown by Tests Made on Hematite.*

Pole-Distance. Inches.	Weight of Mineral. Grammes.	Pull. Grammes.	Flux. Lines per 1.2668 Sq. Cm.	Difference.
8,	1.38	0.909	2679.685	......
8,	1.19	0.836	"	0.073
8,	1.03	0.745	"	0.091
8,	0.85	0.709	"	0.036
8,	0.69	0.636	"	0.073
8,	0.51	0.527	"	0.109
8,	0.34	0.400	"	0.127
8,	0.17	0.154	"	0.246

On reference to Fig. 35, it will be seen that on starting with a certain amount of mineral and decreasing the weight by constantly diminishing fractions of the whole, we get a decrease in the tractive force. From the eight-eighths point (which represents the full amount taken), down to the six-eighths point, there is a gradual decrease; but from the latter point down the decrease becomes irregular, by reason both of a decrease of mass and an increase of divergence of lines of force. The pan being only partly filled, the center of gravity of the mass tested was nearer the pole-piece, in the tests of the smaller quantities. Connecting the points would give very nearly a continuous curve; but a straight line, *o a*, would probably represent the truth more nearly, as eliminating the effect of this lowering of the center of gravity.

We may therefore say that the tractive force varies directly with the mass or weight.

FIG. 35

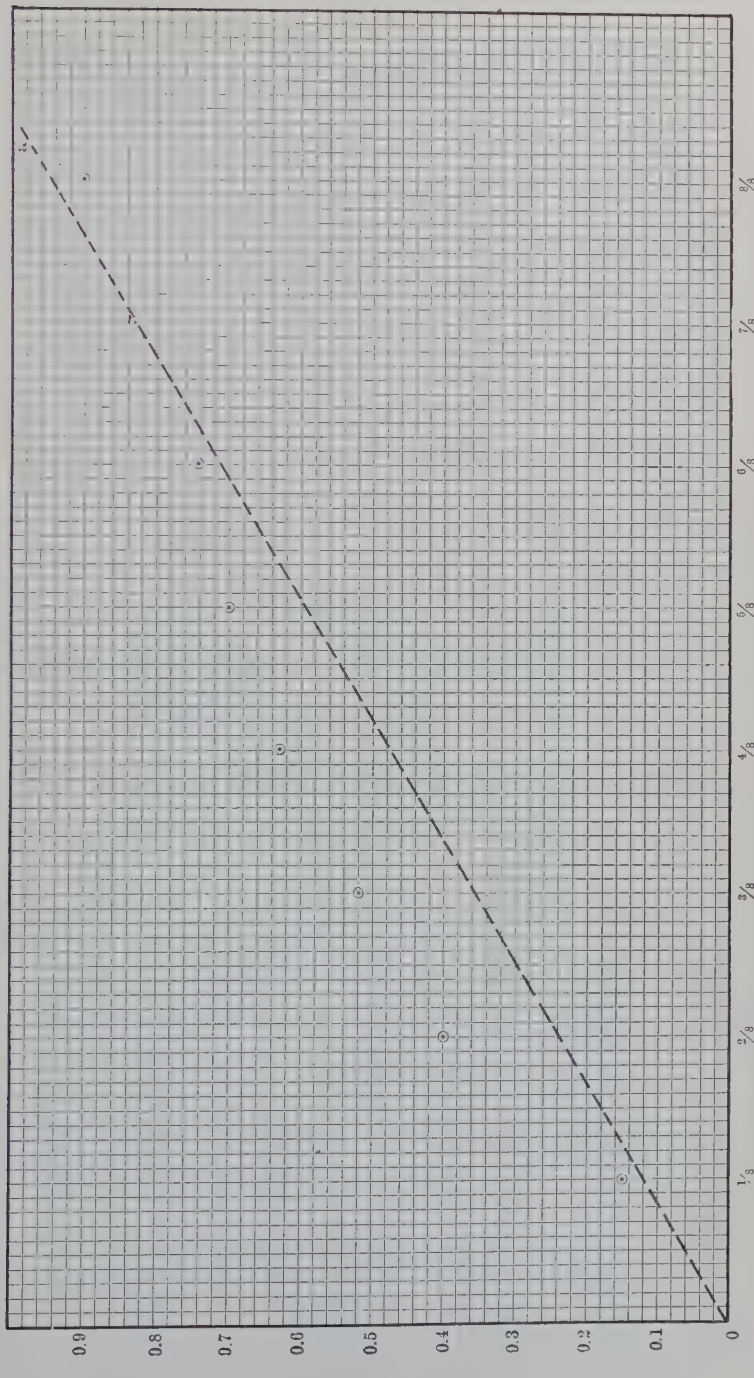


Diagram Showing Variation in Tractive Force, Due to Varying Weight of Mineral Taken. (See Table VI.)

p. Effect of Varying Pole-Distance.—Tests were made with equal volumes and masses of mineral, and varying pole-distances, but with a constant flux, maintained by increasing the current as the pole-distance was changed. The results were:

TABLE VII.—*Variations in Tractive Force Due to Varying Pole-Distance, as Shown by Tests Made on Pyrrhotite.*

Pole-Distance. Inches.	Pull. Grammes.	Pull. Centimeters.	Flux. Lines of Force per 1.2668 Sq. Cm.	Difference.
1, ...	3.181	1.750	2679.685	......
2, ...	3.363	1.850	"	0.182
3, ...	3.454	1.900	"	0.091
4, ...	3.727	2.050	"	0.273
5, ...	3.636	1.950	"	0.091
6, ...	3.454	1.900	"	0.182
7, ...	3.363	1.850	"	0.091
8, ...	3.000	1.650	"	0.363

In Fig. 36 it will be seen that for the first four inches the rise is fairly regular, but beyond the fourth inch there is a sudden, irregular fall, evidently due to the decreasing divergence of the lines of force. When the poles are close together, the divergence is slight, increases to a maximum at some point between 4 and 5 in. pole-distance, and decreases as the poles are further separated. This is shown graphically in Fig. 38.

To what extent the outside field influences the distribution and action of the enclosed portion cannot be said at present. That it does have some effect is certain. The line A B will represent the variation.

We conclude, therefore, that, within the limits indicated in Figs. 36 and 38, the tractive force varies directly with the divergence of the field, and hence with the pole-distance.

q. Effect of Varying Magnetization.—With equal volumes and pole-distances, but varying magnetization, a series of tests gave the following results:

TABLE VIII.—*Variations in Tractive Force Due to Varying Magnetization, as Shown by Tests Made on Hematite.*

Pole-Distance. Inches.	Pull. Grammes.	Flux. Lines of Force per 1.2668 Sq. Cm.	Difference.
3.218	0.636	1617.811	....
3.218	0.972	3215.622	0.3364
3.218	1.717	4823.433	0.7445
3.218	2.336	6431.244	0.6191
3.218	3.109	8039.055	0.7727

In Fig. 37 it will be seen that the plotting is quite regular, and a straight line will represent very well the variation of

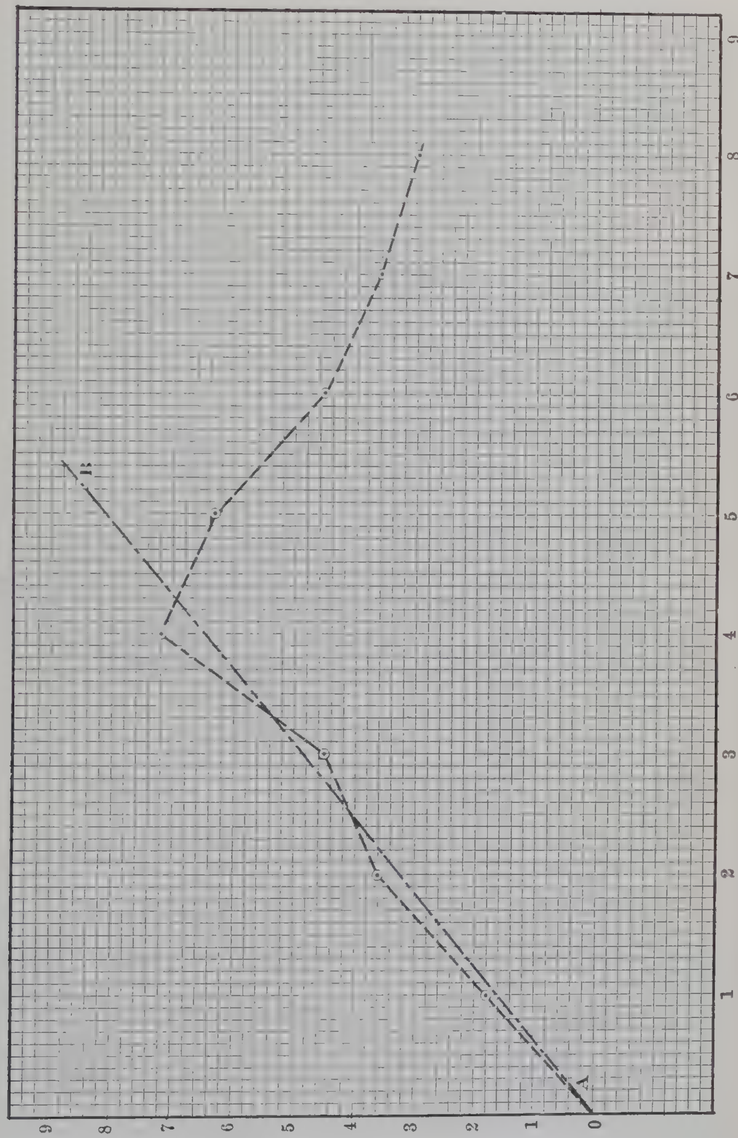


FIG. 36

Diagram Showing Effect on Tractive Force by Varying Pole-Distance. (See Table VII.)

tractive force due to varying flux. The tractive force thus varies directly with the magnetization or flux.

r. Effect of Varying Size, all Other Quantities Being Constant.— Cast-iron was ground and sized between certain limits to deter-

mine the variation of tractive force with reference to size. The cast-iron was crushed and reduced to the desired size in a diamond mortar. It was found that grains so produced are rounded, the sharp edges having been broken off. The crushed material, as taken from the mortar, was sized between the following limits of meshes to the inch: 190 to 70, 70 to 36, 36 to 12, 12 to 8, and 8 to 5. Tests were then made on the sizes by both the rod- and the traction-method.

FIG. 37

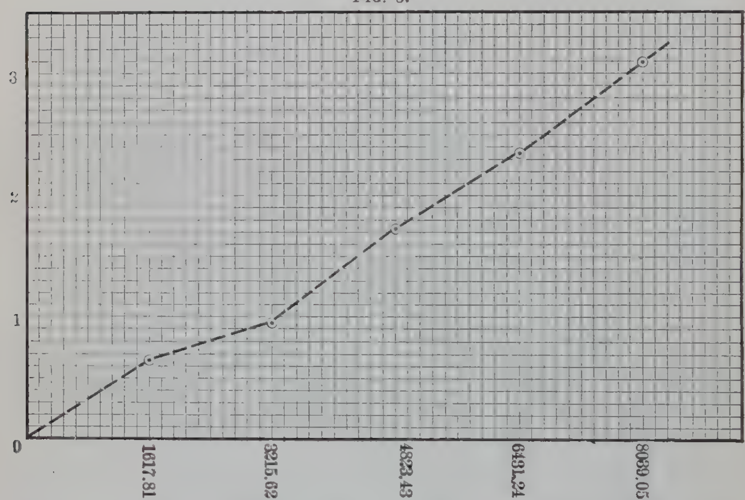


Diagram Showing Variation of Tractive Force With Varying Magnetization. (See Table VIII.)

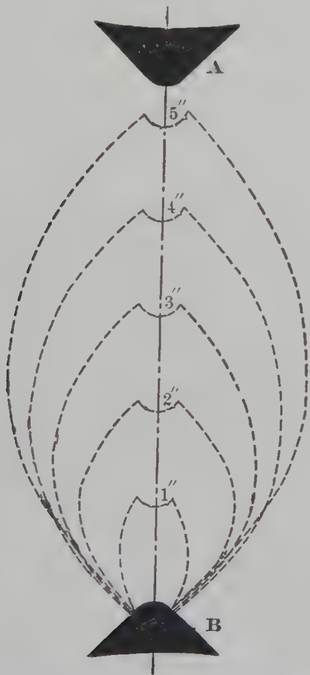
With the rod-method the following results were obtained:

TABLE IX.—*Variations in Tractive Force Due to Varying Size of Material, as Shown by Tests Made on Cast-Iron by the Rod-Method.*

No.	Form.	B (Flux in Iron per 1.2668 Sq. Cms.)	Weight. Grammes.	μ.	H.
1.	Filings, . . .	1452.385	3.84	1.868	777.107
2.	Turnings, . .	1552.138	4.17	1.982	777.107
3.	Unsized below 190-mesh,	1617.811	5.20	2.068	777.107
4.	Sized 70-mesh, .	1751.794	5.45	2.241	777.107
5.	Sized 36-mesh, .	1779.592	5.53	2.276	777.107
6.	Sized 12-mesh, .	1806.388	5.72	2.327	777.107
7.	Sized 8-mesh, . .	1885.779	5.74	2.413	777.107
8.	Sized 5-mesh, . .	2019.762	5.78	2.586	777.107
9.	Unsized, . . .	2411.716	7.28	3.103	777.107
10.	Rod, . . .	4797.760	12.38	6.120	777.107

From the above table it will be seen that the permeability increases from 2.241 to 2.586 with the sized material. The unsized material passing through a 190-mesh sieve gives a permeability even lower than that of the size of 190 to 70. It is fairly uniform, however, as little fine was made in the mortar. The unsized material, as taken from the mortar, gives a higher permeability than that of the largest size: 3.103 as compared with 2.586.

FIG. 38



Variations in Divergence of Magnetic Field Due to Varying Pole-Distance.

Filings and turnings were also tested, giving a permeability of 1.868 and 1.982 respectively. The very irregular shape is probably responsible for the drop, which would be produced by a leakage of the flux. The effect of size is also noticeable here—the finer filings having a lower permeability than the larger, tubular-shaped turnings.

Tests were made on a rod turned from the same piece of cast-iron, giving a permeability of 6.120.

The investigation was carried one step further: A wrought-iron rod, a laminated rod and filings from the same rod were

tested by the rod-method, with the following results: For a rod of the best soft Swedish wrought-iron, μ was determined as 7.177; for a laminated rod of Russian sheet-iron, wrapped in spiral form longitudinally, it was 5.887; for filings from the soft iron rod, it was 2.580.

Thus the results obtained from both cast-iron and wrought-iron indicate that both the size and the shape of the material have a marked effect upon its permeability.

The same sizes used in the rod-method were used in the traction-method, and gave similar, although possibly more significant, results.

The tests were made as before, on equal volumes of the sized materials, and the tractive force was measured as already described.

TABLE X.—*Tests, as in Table IX., Made by the Traction-Method Upon Crushed Cast-Iron.*

Mesh.	Weight. Grammes.	Pull. Grammes.
1. Unsized below 5,	2.08	1766.65
2. Sized 8 to 5,	1.85	1561.56
3. Sized 36 to 12,	1.82	1519.57
4. Sized 70 to 36,	1.58	1277.59
5. Sized 190 to 70,	1.52	1124.36
6. Unsized below 190,	1.31	917.94
7. Filings,	0.97	702.36

With this method, as with the rod-method, the unsized material stands highest, then the sized products, next the unsized below 190-mesh to the inch, lastly the filings. This variation is due to the varying percentage of air-space. For sized and unsized materials the per cents. of air-space are 50 and 38 respectively.*

Tests were then made on minerals crushed and sized, as shown in the following table:

TABLE XI.—*Tests, as in Table X., Made Upon Other Minerals.*

No.	Mineral.	Sized Mesh.	Weight. Grammes.	Pull. Grammes.
1.	Pyrite,	100 to 70	1.12	2.250
2.	Pyrite,	70 to 36	1.17	2.150
3.	Pyrite,	70 to 12	1.16	1.925
4.	Pyrite,	12 to 6	1.03	1.650

* P. Rittinger's *Taschenbuch der Aufbereitungskunde*, i., p. 41.

1. Pyrrhotite, . . .	190 to 60	1.16	5.725
2. Pyrrhotite, . . .	60 to 30	1.22	4.210
1. Galena, ...	190 to 60	1.82	0.300
2. Galena, ...	60 to 24	1.87	0.260
3. Galena, ...	36 to 12	1.62	0.200
4. Galena, ...	12 to 6	1.55	0.280

The results obtained with the minerals tested are just the reverse of what was obtained for iron, that is, the tractive force increases as the size decreases.

The three minerals chosen, pyrite, pyrrhotite and galena, are fair representatives of the minerals with respect to their magnetic properties. Pyrrhotite is one of the most highly magnetic, and galena one of the least magnetic, of minerals, while pyrite occupies a position midway between them. Pyrrhotite and pyrite give concordant results, while galena follows in a general way, but is more irregular.

The radically different results obtained with cast-iron and with these minerals may be partially accounted for by (*a*) the higher susceptibility of iron, and (*b*) the columnar form assumed by it in the magnetic field.

Just how far this columnar form of materials tested would affect the tractive force is difficult to say, but it must have some appreciable effect. The columnar form varies with the size of the material tested.

For minerals, then, it may be said that the tractive force varies with the size—the smaller the size, the higher the tractive force.

s. Summary.—From the above determinations the following conclusions may be drawn:

The tractive force varies directly as (1) the mass or weight of mineral (w); (2) the pole-distance (d); (3) the magnetization (F); and (4) the susceptibility (S).*

We may then write

$$T = \frac{S \sigma F w}{K},$$

when σ is the divergence of the field, and K a constant, determined from cast-iron, and used as a basis for comparison.

Solving for S, we have

* $S = \frac{I}{H}$. I varies directly as d, hence the tractive force (T) varies as S.

$$S = \frac{T K}{\sigma F w}.$$

But σ varies as the pole-distance d; hence

$$S = \frac{T K}{d F w}.$$

Substituting this value of S in the formula for permeability, $\mu = 1 + 4\pi S$, we have

$$\mu = 1 + \frac{4\pi T K}{d F w},$$

and taking $\mu = 2.068$ (the permeability of cast-iron) and $K = 4.109$, the formula for determining the tractive force will become

$$\mu = 1 + 51.6353 \frac{T}{d F w}.$$

This empirical formula will give the permeability of substances as compared with cast-iron crushed and unsized, below 190 mesh, assuming the permeability of cast-iron to be 2.068 and that of air to be 1.

As previously stated, the results obtained are comparative, being compared with cast-iron. The comparison is based on cast-iron for three reasons: (a) because it was the only available material which could be reduced and sized in a similar manner as the minerals; (b) because it could be tested by both the rod- and the traction-method; (c) because the value of the permeability found could be used to deduce a formula based upon data obtained by the traction-method.

That the value of the permeability thus found is low for highly magnetic substances, has been demonstrated. It may be very near the actual value for the less magnetic substances. For the diamagnetic materials it probably gives a value a little too high.

What the formula is intended to express is the permeability of minerals as compared with a known value of iron reduced to the same physical state as the ores, assuming the permeability of air to be unity.

III. The Relative Magnetic Permeability of Various Minerals.

The table on the following pages contains not only the permeability of the minerals and metals tested, but the data from which the calculations were made. In the last column the tractive force expressed in percentage is of the weight of mineral.

The specimens of the minerals named in the above-mentioned table came from the following localities (where several localities are named, they are placed in the order occupied by the corresponding tests in the table):

Magnetite, Port Henry, Essex Co., N. Y.; *Franklinite*, Franklin Furnace, Sussex Co., N. J.; *Ilmenite*, Edge Hill, Montgomery Co., Pa.; *Pyrrhotite*, Stobie mine, Sudbury, Ontario, Canada; and Gap mine, Lancaster Co., Pa.; *Zircon*, Norway; Green River (Hendersonville), Henderson Co., N. C.; and Egansville, Renfrew Co., Ontario, Canada; *Hematite*, Lake Superior; Iron Mt., Minn.; Vermillion Range, St. Louis Co., Minn.; Iron Mt., Mo.; and Cumberland, England; *Corundum*, Jackson Co., N. C.; Gaston Co., N. C.; Lehigh Co., Pa.; East Indies; *Siderite*, Roxbury, Litchfield Co., Conn.; Allevand, France; *Rhodonite*, Franklin Furnace, N. J.; *Limonite*, Nova Scotia; Fleetwood, Berks Co., Pa.; *Pyrolusite*, Thuringia; and Bartow Co., Ga.; *Pyrite*, French Creek mines, Chester Co., Pa.; Island of Elba; Rio Tinto, Spain; *Manganite*, Bridgeville, Pictou Co., Nova Scotia; *Calamine*, Friedensville, Lehigh Co., Pa.; *Sphalerite*, Freiberg, Saxony; Iowa; Joplin, Jasper Co., Mo.; *Dolomite*, Cumberland, England; Guanajuato, Mexico; Sing Sing, Westchester Co., N. Y.; Berkshire Co., Mass.; *Quartz*, Maine; Kerguelen Island, South Indian Ocean; Chester Co., Pa.; *Rutile*, Magnet Cove, Ark.; Graves Mt., Lincoln Co., Ga.; *Cerussite*, Broken Hills mines, N. S. W.; *Gypsum*, Owasco, Cayuga Co., N. Y.; Derbyshire, Eng.; Grand Rapids, Mich.; *Talc*, Lafayette, Montgomery Co., Pa.; Swain Co., N. C.; Cherokee Co., N. C.; Marietta, Ga; *Molybdenite*, Frankford, Pa.; Tellemarken, Norway; Armidale, N. S. W.; *Cerargyrite*, Silver City, Grant Co., N. M.; *Argentite*, Guanajuato, Mexico; *Magnesite*, Regla, Cuba; Lancaster Co., Tex.; *Orpiment*, Felsobanya, Hungary; *Bornite*, New South Wales; Union Bridge, Carroll Co.,

TABLE XII.—*Magnetic Permeability of Various Minerals.*

Mineral.	Weight. (w) Grammes.	Pole-Distance. (d) Centim.	Flux. (F)	Tractive Force. (T) Grammes.	Permeability. (μ)	T in Per Cent. of w.
Iron	1.41	4.625	6967.181	1023.741	2.1617	72605.81
Steel	1.36	"	"	978.742	2.1532	71966.17
Magnetite	1.08	"	"	314.712	1.4669	29140.00
Franklinite	1.16	"	"	297.731	1.4112	23942.15
Ilmenite	.95	"	"	175.752	1.2871	18500.21
Pyrrhotite	1.08	"	"	52.742	1.0782	4898.48
"	.99	.828	10924.716	13.454	1.0775	1358.89
Zircon	1.04	"	"	5.345	1.0293	513.90
"	.94	.906	10852.724	.758	1.0042	80.21
"	1.08	.828	10924.716	.363	1.0019	33.61
Hematite	1.19	"	"	5.045	1.0242	423.94
"	1.49	"	"	4.365	1.0167	292.95
"	.81	"	"	2.272	1.0160	280.20
"	.81	.921	10835.732	1.876	1.0119	230.86
"	1.61	.828	10924.716	2.302	1.0081	149.90
Corundum	.82	"	"	3.636	1.0253	443.42
"	.83	"	"	1.218	1.0083	146.74
"	.85	.921	10835.732	.587	1.0035	69.05
"	.80	.828	10924.716	.263	1.0018	32.87
Siderite	.87	.921	10835.732	3.941	1.0234	452.98
"	.85	.828	10924.716	3.171	1.0213	373.05
Rhodonite	.66	.921	10835.732	2.247	1.0176	340.45
Limonite	.73	.828	10924.716	1.271	1.0099	174.10
"	.78	"	"	1.345	1.0098	172.43
Pyrolusite	.73	"	"	1.134	1.0088	155.34
"	.89	"	"	1.218	1.0078	136.85
Pyrite	1.03	"	"	1.163	1.0064	112.91
"	1.04	"	"	.400	1.0020	38.46
"	1.02	.906	10852.724	.294	1.0015	28.82
"	1.03	.828	10924.716	.127	1.0007	12.33
Manganite	.77	.921	10835.732	.961	1.0061	124.80
Calamine	.75	1.000	10450.771	.896	1.0059	119.46
Sphalerite	.90	.828	10924.716	.909	1.0057	101.00
"	.97	"	"	.309	1.0018	31.84
"	.94	.921	10835.732	.127	1.0007	13.51
Dolomite	.64	.828	10924.716	.636	1.0056	99.37
"	.62	"	"	.290	1.0026	46.77
"	.63	.921	10835.732	.225	1.0018	35.71
"	.67	.828	10924.716	.181	1.0015	27.01
"	.67	"	"	.181	1.0015	27.01
Quartz	.56	.921	10835.732	.596	1.0055	106.42
"	.64	.828	10924.716	.609	1.0054	95.15
"	.63	"	"	.245	1.0022	38.88
Rutile	.90	.921	10835.732	.927	1.0053	103.00
"	.98	.828	10924.716	.836	1.0048	85.30
"	.97	"	"	.518	1.0030	53.40
Cerussite	1.46	"	"	1.363	1.0053	93.35
"	1.15	.906	10852.724	.410	1.0018	35.65
Gypsum	.43	.828	10924.716	.254	1.0033	59.07
"	.51	"	"	.109	1.0012	21.37
"	.49	"	"	.054	1.0006	11.02
"	.48	.921	10835.732	.051	1.0005	10.62
Garnet	.76	.828	10924.716	.636	1.0047	83.60
Talc	.41	.921	10835.732	.309	1.0039	75.36
"	.44	.828	10924.716	.100	1.0013	22.72
"	.37	"	"	.090	1.0013	24.32

TABLE XII.—*Continued.*

Mineral.	Weight. (w) Grammes.	Pole-Distance. (d) Centim.	Flux. (F)	Tractive Force. (T) Grammes.	Permeability. (μ)	T in Per Cent. of w.
Talc	.62	.828	10924.716	.090	1.0008	14.51
Molybdenite	.71	"	"	.472	1.0037	66.47
"	.73	"	"	.363	1.0028	49.73
"	.89	.921	10835.732	.268	1.0015	30.11
Cerargyrite	1.10	1.000	10450.771	.671	1.0033	61.00
Argentite	1.06	.906	10852.724	.660	1.0032	62.24
Magnesite	.70	.828	10924.716	.390	1.0031	55.71
"	.64	"	"	.072	1.0006	11.25
Orpiment	.25	.921	10835.732	.140	1.0028	56.00
Bornite	1.04	.828	10924.716	.509	1.0027	48.94
"	1.00	.921	10835.732	.418	1.0021	41.80
Apatite	.69	"	"	.350	1.0026	50.72
Willemite	.94	"	"	.520	1.0024	55.31
Tetrahedrite	1.00	.828	10924.716	.454	1.0025	45.40
"	1.09	"	"	.463	1.0024	42.47
"	1.09	.921	10835.732	.500	1.0023	46.05
Fluorite	.81	.828	10924.716	.254	1.0017	31.11
"	.74	.921	10835.732	.149	1.0010	20.13
Cuprite	1.14	.906	10852.724	.358	1.0016	31.40
"	1.34	.828	10924.716	.081	1.0003	6.04
Arsenopyrite	1.24	.906	10852.724	.400	1.0017	32.25
Chalcopyrite	.99	.921	10835.732	.316	1.0016	31.91
Celestite	.94	"	"	.225	1.0012	23.93
Zincite	1.26	"	"	.289	1.0012	22.93
Chalcocite	.95	"	"	.218	1.0012	22.94
"	.98	.828	10924.716	.163	1.0009	16.53
Cinnabar	1.21	.921	10835.732	.283	1.0012	23.38
Orthoclase	.58	"	"	.170	1.0011	29.31
"	.62	.828	10924.716	.009	1.0001	.16
Smithsonite	1.08	"	"	.181	1.0009	16.76
"	.94	.906	10852.724	.134	1.0007	14.25
Stibnite	.85	.828	10924.716	.109	1.0007	12.82
"	.89	"	"	.090	1.0006	10.11
"	.91	.921	10835.732	.078	1.0004	8.57
Cryolite	.68	"	"	.089	1.0006	13.08
Enargite	.91	"	10825.732	.117	1.0006	12.86
Senarmontite	1.16	1.000	10450.771	.143	1.0006	12.32
Galena	1.64	.906	10852.724	.200	1.0006	12.19
"	1.70	.828	10924.716	.109	1.0003	6.41
Niccolite	1.53	.921	10835.732	.147	1.0005	9.60
Calcite	.61	"	"	.049	1.0004	8.03
Witherite	.92	1.000	10450.771	.038	1.0002	4.12
Barite	1.09	.828	10924.716	.000	1.0000	0.00
"	1.14	"	"	.000	1.0000	0.00
"	1.08	.921	10835.732	.045	.9999	4.16
"	1.08	.828	10924.716	.018	.9998	1.66
Graphite	.27	.921	10835.732	.049	.9990	18.14
Bismuth	1.22	1.000	12862.588	.018	.9999	1.47

Md.; *Apatite*, Evansville, Renfrew Co., Ontario, Can.; *Willemite*, Franklin Furnace, N. J.; *Tetrahedrite*, Peru, S. A.; England; Rosebery District, Tasmania; *Fluorite*, Jefferson Co., N. Y.; Rosiclaire, Hardin Co., Ill.; *Cuprite*, Copper Queen mine, Bis-

bee, Ariz.; Cornwall, Eng.; *Arsenopyrite*, Acton, York Co., Me.; *Chalcopyrite*, S. Australia; *Celestite*, Strontian Island, Lake Erie, O.; *Zincite*, Franklin Furnace, N. J.; *Chalcocite*, Anaconda mine, Butte, Mont.; Broken Hill, N. S. W.; *Cinnabar*, New Almaden, Cal.; *Orthoclase*, Elam, Delaware Co., Pa.; Alexandria, N. Y.; *Smithsonite*, Mineral Point, Wis.; Graphic mines, Kelly, N. M.; *Stibnite*, Germany; Armidal, N. S. W.; Juab Co., Utah; *Cryolite*, Ivigtut, Greenland; *Enargite*, Butte, Mont.; *Galena*, Joplin, Mo.; Galena, Ill.; *Niccolite*, Bebra, Hesse, Germany; *Calcite*, Joplin, Mo.; *Barite*, Bartow Co., Ga.; Logan Co., Col.; Cheshire, Conn.; Saxony; *Graphite*, Ceylon; *Witherite*, Alston Moor, Cumberland, Eng.

The marked variations of permeability noted in the same mineral, but from different localities, are probably due, in most cases, to varying percentages of iron, either as a part of the composition or as an impurity. This is especially noticeable in a few cases where there are marked variations.

Note on Cheap Gold-Milling in Mexico.

BY HENRY F. COLLINS, CHIAPAS, MEXICO.

(Richmond Meeting, February, 1901.)

THE following notes on the cheap milling of a soft low-grade ore-body in the State of Chiapas, Mexico, may be of interest. The ore-body in question was worked, not by itself, but incidentally in connection with a large extraction of concentrating-ore; and one 10-stamp battery of a 30-stamp mill used for re-crushing tailings, and provided with copper-plates, was set aside for the treatment of this particular ore, of which, during a period of 17 months, 10,274 tons, of 2240 lbs. each, were handled.

Description.—The ore-body consisted of that portion of a mass of decomposed garnet-rock of igneous origin, which, near its contact with another igneous mass, composed chiefly of the mineral wollastonite in a nearly pure state, had been permeated by solutions, depositing irregularly, throughout it, quartz, chal-

cedony, silicate and carbonate of copper, gold, and much hydrated oxide of iron. The portion thus impregnated and rendered gold-bearing averaged about 30 ft. in width; and assays throughout this width varied from 0.05 oz. up to 0.65 oz., and in one case even 0.9 oz., the average being about 0.20 oz. of gold per ton of 2240 lbs. The contact-zone was exposed on the top of a narrow neck joining two very steep hills, and ran at right angles to the axis of the ridge, so that at the surface it was only about 40 ft. long.

Mining.—The accessible end of the ore-body was at the top of a cliff about 100 ft. vertically above the end of a branch-track from the mill. From this point a short drift was run, about 40 ft. below the summit of the ridge, a raise was put up, and a shoot was arranged, so that the stuff could be quarried in open-cut, readily loaded into the car running in the drift, and, from this car, dumped over the cliff. Since about 90 per cent. of the material broken was friable ferruginous garnet-rock, and only 10 per cent. was quartz and chalcedony (both of which, though extremely hard, were fortunately much fissured), but little explosive was required, and that mostly in large blasts, made to loosen the mass. The fall from the top to the bottom of the 100-ft. cliff effectually broke up most of the large pieces of rock. At the latter point the heap was shoveled into cars and trammed to the mill, a distance of some 350 yards.

Milling.—The material was tipped over a grizzly, 1.5 in. between bars. The proportion of quartz, etc., which did not pass through was comparatively small; one boy, with occasional help, being able to spall the lumps and shovel them again through the grizzly. Thence it was delivered to the mill-bin, which held about 24 hours' supply for the battery.

The stamps weighed 750 lbs., and dropped 5 in. 100 times per minute. Shoes and dies were of Sandicroft forged steel. The screens were of copper-wire, and at first of 20-mesh size; but as the difficulty of saving the gold became evident, the ore was crushed more finely, first through 30- and finally through 40-mesh screens. There were no inside plates, though quicksilver was fed into the mortars; and it proved exceedingly difficult to keep in condition the outside plates (silver-plated); both green scum and black spots forming rapidly and persist-

ing obstinately, while there was a strong tendency to "scour." Of the gold shown to exist by assay the percentage extracted was low (only 30 per cent.). Experiments with cyanide, however, showed an enormous cyanide-consumption, with an extraction not exceeding 50 per cent., which was not considered encouraging. A large number of panning-tests showed that the proportion of coarse gold obtained in the heavy black magnetite sand was small, and that most of the particles were visibly "coated" with hydrated oxide of iron. The bulk of the gold, however, was very fine and "rusty," intimately intermingled with the hydrated oxides of iron, among which, apparently, it had been precipitated. In the testing of samples from some of the richer parts of the deposit, an exceedingly fine brown powder adhered to the bottom of the pan, and although, by reason of its weight, presumed to be gold, manifested none of the characteristics of that metal until heated to low redness, when it acquired a metallic luster. The ignited powder yielded iron to hydrochloric acid in a test-tube, and was evidently precipitated gold, intermingled or coated with precipitated oxide of iron. Ground with quicksilver, it refused to amalgamate completely; and, treated with cyanide before heating, it dissolved very slowly. This is clearly another instance of gold coated with oxide of iron, of similar nature to that described by Messrs. Chatard and Whitehead.*

Cost.—The cost of mining and milling was so low that, in spite of the imperfect extraction, this low-grade ore, yielding an average of only 0.0659 oz. of fine gold, was worked at a profit of nearly 80 cents gold per long ton. The mining, though it involved two and sometimes three handlings, was done for 20.5 cents per ton of 2000 lbs.; and the milling, including all current repairs and due proportion of mill-salaries, for 17.6 cents (no allowance, however, being made for power, since the whole mill, of which the ten stamps formed part, is driven by waterpower). The cost of milling would have been lower but for the isolated situation of the camp, freight to which from New York comes to about $40 gold per ton.

* "An Examination of the Ores of the Republic Gold-Mine, Washington," *Trans.*, xxx., 419.

The total quantity treated, and its yield, may be recapitulated as follows:

Quantity of ore treated, ...	10,274 tons of 2240 lbs.
Total yield of melted bullion, . . .	846.36 oz.
Average fineness, ...	798.5
Total yield of fine gold, ...	677.44 oz.
Yield of fine gold per ton of 2240 lbs., .	0.0659 oz.

The following table gives the detailed cost in Mexican silver of treatment per ton of 2240 lbs., and cost per short ton of 2000 pounds in U. S. currency, with exchange at 48 cents to the dollar (about its average value during the past two years), being added for comparison:

	Mexican Silver, ton of 2240 lbs.		U. S. Currency, ton of 2000 lbs.	
Mining:				
Cost of breaking and tramming:				
Labor, ...	$0.4457		$0.1909	
Explosives, ...	0.0337		0.0145	
Total cost, ...		$0.4794		$0.2054
Milling:				
Labor, white, foremen, etc., .	0.1128		0.0483	
" native, ...	0.0967		0.0415	
Materials:				
Shoes and dies, ...	0.0801		0.0343	
Screens, ...	0.0148		0.0063	
Stems, liners, feeders, etc., . .	0.0371		0.0159	
Belts and driving-gear, . . .	0.0044		0.0019	
Quicksilver, ...	0.0141		0.0061	
Oil, grease, and lighting, . .	0.0343		0.0147	
Sundry tools and materials, . .	0.0175		0.0074	
Total cost, ...		$0.4118		$0.1764
Total cost of mining and milling, .		$0.8912		$0.3818

Specifications for Steel Rails.

BY W. R. WEBSTER, PHILADELPHIA, PA.

(Richmond Meeting, February, 1901.)

Opinions still differ widely concerning the requirements, chemical and physical, which should be expressed in specifications for steel rails, in order to secure results satisfactory to both manufacturers and purchasers.

Sir Lowthian Bell is reported as saying last summer, at the London meeting of the American Society of Civil Engineers, that "as he had been twenty-five years a manufacturer of rails, and twenty-five years a director in the Northeastern Railway, he represented both maker and user, and he had at his disposal 35,000 analyses to go upon, in making deductions. From these he could prove, and disprove, everything that could be said for or against any composition of a rail,—a facility beloved by the expert."

The Committee of the British Board of Trade adopted in its report of May, 1900,* the following, with other conclusions submitted by Sir William C. Roberts-Austen and Professor Unwin:

"The evidence before the Committee indicates what the limiting proportions of carbon, sulphur, phosphorus, manganese and silicon should be. As regards the influence of phosphorus, it is pointed out that, in a broad sense, brittleness of steel does not depend on the total amount of phosphorus present, as that element may exist in steel in at least two different forms, one of which is comparatively innocuous.

"It is very important that all who are responsible for the manufacture or use of steel rails should realize that steel is not the homogeneous mass it is often supposed to be, but possesses a complex structure. The nature of this structure will vary greatly with the mechanical and thermal treatment to which the metal has been subjected. The durability of the rail depends in no small measure on its structure, which may, if the specimens of steel have been suitably prepared, be revealed by the microscope. The peculiar structure of the St. Neots rail, for instance, can be exactly imitated."

Also the following, with others, submitted by Professor Unwin, Sir Benjamin Baker and Professor Kennedy:

"It is very desirable that the mechanical tests to which rails are subjected should be as far as possible standardized in connection with (1) the weight; (2) the section; and (3) the chemical composition of the rail."

After expressing agreement with the conclusions of the sub

* Steel Rails: Report of the Committee appointed by the Board of Trade to Enquire into the Loss of Strength in Steel Rails through Use in Railways. (Parliamentary Blue Book [Papers by Command, No. 174], May, 1900, pp. 7, 8.) (The Committee consisted of Lord Blythswood, *Chairman*, and the following distinguished engineers and experts: Sir Benjamin Baker, Sir Isaac Lowthian Bell, Prof. Wyndham Dunstan, Prof. A. B. W. Kennedy, Maj. F. A. Marindin, Mr. E. P. Martin, Prof. Sir William C. Roberts-Austen, Dr. Thomas E. Thorpe, Prof. W. C. Unwin and Mr. E. Windsor Richards.)

committees, the report adds, that as regards chemical composition, the Committee does not think it desirable "to insist upon too high a proportion of carbon, manganese or silicon in the steel, having regard to the ordinary contingencies of manufacture, and the greater susceptibility of high-carbon steel to thermal influences."

Appendix VII. (p. 74 of the Report) gives the following chemical specifications for rails, proposed by Mr. E. Windsor Richards and approved by Mr. E. P. Martin:

	Minimum. Per Cent.		Maximum. Per Cent.
Carbon,	0.35	to	0.50
Silicon,	0.05	"	0.10
Sulphur,	0.04	"	0.08
Phosphorus,			0.08
Manganese,	0.75	"	1.00

This subject of steel rails constitutes but a single branch of the larger subject, for the investigation of which the International Association for Testing Materials was organized in 1895, at a conference held in Zurich, Switzerland—following a series of similar conferences, held at Dresden (1884), Berlin (1886), Munich (1888), and Vienna (1893). In historic justice, the conference of 1882 at Munich, and its chief promoter, John Bauschinger, should be mentioned as practically originating the movement.* The successive conferences had gradually acquired an international character; and at the Zurich conference of 1895 all European countries, except Turkey, were represented, as was also the United States (by an army officer and a delegate from the American Society of Mechanical Engineers). The opportunity thus presented for the formal organization of an International Association was evidently too good to be lost. The objects of the Association, as stated in its statutes, are "the development and unification of standard methods of testing for the determination of the properties of

* For an interesting account of this movement, see the address of Prof. Mansfield Merriman, Chairman of the American Section of the International Association for Testing Materials, delivered at the second annnal meeting of that Section, at Pittsburgh, Pa., August 15, 1899, and published, September, 1899, in its Bulletin No. 4.

the materials of construction and of other materials, and also the perfection of apparatus for that purpose."

The activity of the American Section of the Association has been creditably shown in many ways. As regards the physical and chemical tests of iron and steel, its work is exhibited in its Bulletins 8 to 17, inclusive, which give the specifications proposed by the American Branch of the International Committee No. 1, for the various forms of iron and steel included in the following list (in which the number of the corresponding Bulletin follows, in parenthesis, the name of each class of material): structural steel for bridges and ships (8); for buildings (9); open-hearth boiler-plate and rivet-steel (10); steel rails (11); splice-bars (12); axles (13); tires (14); forgings (15); castings (16); wrought-iron (17).

Concerning these proposed specifications, it need only be said that they have been approved by vote of the Committee as representative of the best American practice, and are submitted for discussion to the technical societies and individual experts of the United States.

In all these departments, the Institute is perhaps best fitted of all our technical societies to discuss at least the metallurgical questions involved, since it comprises not only leading metallurgical chemists and engineers, but also many civil and mechanical engineers, competent to consider the conditions presented by each special use of the material. But it has been deemed advisable not to attempt too much; and therefore, while contributions on other branches of the general subject will doubtless be hereafter, as heretofore, acceptable in our *Transactions*, it is specially desired that our members shall give attention to the specifications for rails, given in the appendix to this paper. The following list of papers and discussions, compiled from the *Transactions*, will show how early the Institute took up the subject of the relation between the chemical composition and the physical qualities of the various compounds of iron, and how important have been its contributions to the literature of that subject. I give it here, in the hope that it may stimulate our members to continue the work so well begun, and retain for the Institute in this field the deserved reputation which it now enjoys:

Papers and Discussions on the Nature, Composition, Qualities, Uses, etc., of Iron and Steel, Contained in the Transactions of the American Institute of Mining Engineers, since its Organization in 1871. Arranged in Chronological Order.

Title.	Author.	Volume.	Year.
Manufacture of Iron and Steel Rails,	John B. Pearse,	I.	1872–3
Rolling *versus* Hammering Ingots,	A. L. Holley,	I.	1872–3
Tests of Steel,	A. L. Holley,	II.	1873–4
Certain Mechanical Changes in Bessemer Steel,	A. MacMartin,	II.	1873–4
Investigations on Iron and Steel,	Prof. T. Egleston,	III.	1874–5
Phosphorus and Carbon in Iron and Steel,	Dr. R. W. Raymond,	III.	1874–5
Annealing Spiegeleisen,	Dr. R. W. Raymond,	III.	1874–5
Some Pressing Needs of Our Iron and Steel Manufacturers,	A. L. Holley,	IV.	1875–6
What is Steel?	A. L. Holley,	IV.	1875–6
What Steel Is,	Frederick Prime, Jr.,	IV.	1875–6
The Effect of Manganese in Bessemer Metal,	Dr. August Wendel,	IV.	1875–6
The Commercial and Scientific Nomenclature of Iron,	William Metcalf,	V.	1876–7
The Properties of Iron Alloyed with Other Metals,	G. H. Billings,	V.	1876–7
The Nomenclature of Iron,	H. M. Howe,	V.	1876–7
The Endurance of Iron Rails,	W. E. C. Coxe,	V.	1876–7
The Strength of Wrought Iron as Affected by its Composition and its Reduction in Rolling,	A. L. Holley,	VI.	1877–8
The Chemical Composition and Physical Properties of Steel Rails,	Dr. Charles B. Dudley,	VII.	1878–9
Does the Wearing Power of Steel Rails Increase with the Hardness of the Steel?	Dr. Charles B. Dudley,	VII.	1878–9
On an Apparatus for Testing the Resistance of Metals to Repeated Shocks,	William Kent,	VIII.	1879–80
The Law of Fatigue and Refreshment of Metals,	Prof. T. Egleston,	VIII.	1879–80
The Wearing Capacity of Steel Rails in Relation to their Chemical Composition and Physical Properties,	Dr. C. B. Dudley,	IX.	1880–1
The Amount of Manganese Required to Remove the Oxygen from Iron after it has been Blown in a Bessemer Converter,	S. A. Ford,	IX.	1880–1
Note on Manganese in Bessemer Rail-Steel,	John W. Cabot,	X.	1881–2

Title.	Author.	Volume.	Year.
Iron and Steel as Materials of Construction,	General Discussion,	X.	1881–2
Notes on the Relation of Manganese and Carbon in Iron and Steel,	Alexandre Pourcel,	XI.	1882–3
The Management of Structural Steel,	Albert F. Hill,	XI.	1882–3
Microscopic Analysis of the Structures of Iron and Steel,	J. C. Bayles,	XI.	1882–3
Open-Hearth Steel Charge Made for Boiler Plates,	Alfred E. Hunt,	XII.	1883–4
Physical and Chemical Tests of Steel for Boiler and Ship-plate for the United States Government Cruisers,	Pedro G. Salom,	XII.	1883–4
The Study of Iron and Steel,	J. C. Bayles,	XIII.	1884–5
The Segregation of Impurities in Bessemer Steel Ingots on Cooling,	Prof. B. W. Cheever,	XIII.	1884–5
A Theory to Explain the Cause of Hard Centers in Steel Ingots,	R. Gatewood,	XIII.	1834–5
The Microscopic Structure of Iron and Steel,	F. L. Garrison,	XIV.	1885–6
The Influence of Temperature in Steel Making on the Behavior of the Ingots in Rolling,	John W. Cabot,	XIV.	1885–6
The Manufacture of Steel Castings,	Pedro G. Salom,	XIV.	1885–6
The Homogeneity of Open-Hearth Steel,	H. H. Campbell,	XIV.	1885–6
Mitis Castings of Wrought-Iron and Steel,	P. Ostberg,	XIV.	1885–6
Notes on the Constitution of Cast-Iron,	Dr. C. B. Dudley,	XIV.	1885–6
Recent Failures of Steel Boiler-Plates,	William Kent,	XIV.	1885–6
Soft Steel for Boiler-Plates,	A. E. Hunt,	XIV.	1885–6
Microscopic Structure of Steel Rails,	F. L. Garrison,	XV.	1886–7
Two Conditions of Phosphorus in Iron,	B. W. Cheever,	XV.	1886–7
Certain Conditions in the Manufacture of Steel Rails which may Influence their Life in Service,	F. A. Delano,	XVI.	1887–8
Rail Sections,	F. A. Delano,	XVII.	1888–9
The Wear of Metal as Influenced by its Chemical and Physical Properties,	Dr. C. B. Dudley,	XIX.	1890–1
Aluminum in Steel Ingots,	Prof. J. W. Langley,	XX.	1891
The Tests and Requirements of Structural Wrought-Iron and Steel,	A. E. Hunt,	XX.	1891
The Making of Specifications for Structural Material,	Dr. C. B. Dudley,	XXI.	1892–3
Note on Manganese Steel,	H. M. Howe,	XXI.	1892–3
Observations on the Relations Between the Chemical Constitution and Physical Character of Steel,	W. R. Webster,	XXI.	1892–3

Title.	Author.	Volume.	Year.
Segregation and its Consequences in Ingots of Steel and Iron, . .	A. Pourcel, . . .	XXII.	1893
Microscopic Metallography, . .	F. Osmond, . . .	XXII.	1893
The Microstructure of Steel, . .	A. Sauveur, . . .	XXII.	1893
The Open-Hearth Process, . .	H. H. Campbell, . .	XXII.	1893
Further Observations on the Relation Between the Chemical Constitution and the Physical Character of Steel, ...	W. R. Webster, . .	XXIII.	1893
The Heat-Treatment of Steel, . .	H. M. Howe, . .	XXIII.	1893
The Microstructure of Ingot-Iron in Cast Ingots, ...	A. Martens, . . .	XXIII.	1893
Iron Alloys, with Reference to Manganese Steel, ...	R. A. Hadfield, . .	XXIII.	1893
The Physics of Steel, . . .	General Discussion, .	XXIII.	1893
	" "	XXIV.	1894
Pyrometry and the Heat-Treatment of Steel, ...	H. M. Howe, . .	XXIV.	1894
Nickel and Nickel-Steel, . . .	F. L. Sperry, . .	XXV.	1895
Note on a Proposed Scheme for the Study of the Physics of Cast-Iron,	W. R. Webster, . .	XXV.	1895
Specifications for Steel Rails of Heavy Sections Manufactured West of the Alleghanies, . .	Robert W. Hunt, . .	XXV.	1895
Note on Copper in Iron and Steel, .	R. W. Raymond, .	XXVI.	1896
The Microstructure of Steel and Current Theories of Hardening, .	A. Sauveur, . . .	XXVI.	1896
The Relation Between the Chemical Constitution and Physical Character of Steel, ...	W. R. Webster, .	XXVIII.	1898
The Physics of Cast-Iron, . .	General Discussion, .	XXV.	1895
	" "	XXVI.	1896
	" "	XXVII.	1897
	" "	XXVIII.	1898

APPENDIX.

Proposed Standard Specifications for Steel Rails.

(Recommended May, 1900, by the American Branch of Committee No. 1 of the International Association for Testing Materials.)

Process of Manufacture.

1. (*a*). Steel may be made by the Bessemer or open-hearth process.

(*b*). The entire process of manufacture and testing shall be in accordance with the best standard current practice, and special care shall be taken to conform to the following instructions.

(*c*). Ingots shall be kept in a vertical position in pit-heating furnaces.

(*d*). No bled ingots shall be used.

(*e*). Sufficient material shall be discarded from the top of the ingots to insure sound rails.

Chemical Properties.

2. Rails of the various weights per yard specified below shall conform to the following limits in chemical composition :

Weight per yard in lbs.,	50 to 59 +;	60 to 69 +;	70 to 79 +;	80 to 89 +;	90 to 100
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbon, . . .	0.35–0.45	0.38–0.48	0.40–0.50	0.43–0.53	0.45–0.55
Phosphorus shall not exceed, . . .	0.10	0.10	0.10	0.10	0.10
Silicon shall not exceed,	0.20	0.20	0.20	0.20	0.20
Manganese, . . .	0.70–1.00	0.70–1.00	0.75–1.05	0.80–1.10	0.80–1.10

Physical Properties.

3. *Drop-Test.*—One drop-test shall be made on a piece of rail not more than six feet long, selected from every fifth blow of steel. The rail shall be placed head upwards on the supports and the various sections shall be subjected to the following impact tests :

Weight of Rail. Pounds per Yard.		Height of Drop. Feet.
45 to and including	55	15
More than 55 "	65	16
" 65 "	75	17
" 75 "	85	18
" 85 "	100	19

If any rail break when subjected to the drop-test, two additional tests will be made of other rails from the same blow of steel, and if either of these latter tests fail, all the rails of the blow which they represent will be rejected, but if both of these additional test-pieces meet the requirements, all the rails of the blow which they represent will be accepted. If the rails from the tested blow shall be rejected for failure to meet the requirements of the drop-test as above specified, two other rails will be subjected to the same tests, one from the blow next preceding, and one from the blow next succeeding the rejected blow. In case the first test taken from the preceding or succeeding blow shall fail, two additional tests shall be taken from the same blow of steel, the acceptance or rejection of which shall also be determined as specified above, and if the rails of the preceding or succeeding blow shall be rejected, similar tests may be taken from the previous or following blows, as the case may be, until the entire group of five blows is tested, if necessary.

The acceptance or rejection of all the rails from any blow will depend upon the result of the tests thereof.

Test-Pieces and Methods of Testing.

4. *Drop-Testing Machine.*—The drop-testing machine shall have a tup of two thousand (2000) pounds weight, the striking-face of which shall have a radius of not more than five inches, and the test-rail shall be placed head upwards on solid supports three feet apart. The anvil block shall weigh at least twenty thousand pounds, and the supports shall be a part of, or firmly secured to, the anvil.

5. *Sample for Chemical Analysis.*—The manufacturer shall furnish the inspector, daily, with carbon determinations of each blow, and a complete chemical analysis every twenty-four hours, representing the average of the other elements contained

in the steel. These analyses shall be made on drillings taken from a small test-ingot.

Finish.

6. *Section.*—Unless otherwise specified, the section of rail shall be the American standard, recommended by the American Society of Civil Engineers, and shall conform, as accurately as possible, to the templet furnished by the railroad company, consistent with paragraph No. 7, relative to specified weight. A variation in height of one sixty-fourth of an inch less and one thirty-second of an inch greater than the specified height will be permitted. A perfect fit of the splice-bars, however, shall be maintained at all times.

7. *Weight.*—The weight of the rails shall be maintained as nearly as possible after complying with paragraph No. 6, to that specified in contract. A variation of one-half of one per cent. for an entire order will be allowed. Rails shall be accepted and paid for according to actual weights.

8. *Length.*—The standard length of rails shall be thirty feet. Ten per cent. of the entire order will be accepted in shorter lengths, varying by even feet down to twenty-four feet. A variation of one-fourth of an inch in length from that specified will be allowed.

9. *Drilling.*—Circular holes for splice-bars shall be drilled in accordance with the specifications of the purchaser. The holes shall accurately conform to the drawing and dimensions furnished in every respect, and must be free from burrs.

10. *Finish.*—Rails shall be straightened while cold, smooth on head, sawed square at ends, and, prior to shipment, shall have the burr, occasioned by the saw cutting, removed, and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

Branding.

11. The name of the maker, the month and year of manufacture, shall be rolled in raised letters on the side of the web, and the number of the blow shall be stamped on each rail.

Inspection.

12. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

No. 2 Rails.

13. Rails that possess any injurious physical defects, or which for any other cause are not suitable for first quality, or No. 1 rails, shall be considered as No. 2 rails, provided, however, that rails which contain any physical defects which seriously impair their strength shall be rejected. The ends of all No. 2 rails shall be painted, in order to distinguish them.

Secretary's Note.—The above specifications, as published in Bulletin No. 11 of the International Association, were accompanied with an elaborate and highly interesting table, compiled for Committee No. 1, and giving a synopsis of the American rail-specifications now in use, including those proposed by Mr. Hunt in 1895 for western roads, and those proposed by Mr. Webster in 1897 for 60-lb. rails. Two of them are those of the manufacturers (the Carnegie Steel Co., Limited, and the Cambria Steel Co.); and a foot-note to the table says that 155 railroads and their branches buy rails under manufacturers' specifications. The

table contains also the specifications adopted by eleven leading railway companies, namely, the Pennsylvania (and 19 other roads adopting its specifications); Wabash; Louisville and Nashville; Michigan Central; Queen and Crescent (and Cincinnati, N. O., and Tex. Pacific); Northern Pacific; Norfolk and Western; Chicago, Burlington and Quincy; Illinois Central; Southern Pacific; and the Southern Railway.

Since this table has been widely distributed already among those likely to be interested in the subject, it is not deemed necessary to reproduce it here. Members desiring to secure it may address the Secretary, or Mr. Webster, 411 Walnut St., Philadelphia, Chairman of the American Branch of Committee No. 1, or Prof. J. M. Porter, Easton, Pa., Secretary of the American Section of the International Association for Testing Materials.

The table simply represents the present diversity of practice among American railroads; and the Secretary feels warranted by his study of it in saying that it indicates no insuperable difficulty in the way of the adoption of general uniform standards, provided such standards be framed with proper regard to the varying conditions of weight, traffic and section. It need hardly be added that this subject is one of the most important, both technically and commercially, which can engage the attention of American engineers and metallurgists.

For the progress already made in this direction, and for the contribution which the Institute has made to it, both directly through the contributions of its members, and indirectly through the stimulation of corresponding activity in other societies, we should be profoundly and proudly grateful; and we ought to continue with effective vigor the good work in which, heretofore, we have had so much to do.—R. W. R.

Finishing Temperatures for Steel Rails.

BY ROBERT W. HUNT, CHICAGO, ILL.

(Richmond Meeting, February, 1901.)

THERE are certain physical characteristics of steel resulting from its treatment while being formed into useful products which have been, and are, well known to its manipulators; but under the stress of business competition and other controlling influences, all knowledge is not always given either full sway, or even full acknowledgment. Such has been the case in the making of steel rails. It is universally acknowledged that steel rails of heavy sections, made during the last ten years, have not given as good service as the rails of lighter sections produced before that time. While certain fundamental principles of steel-making have been acknowledged, their application to the steel-rail manufacture has been, if not actually denied, completely ignored.

In 1887, Mr. William Metcalf, in his paper presented to the American Society of Civil Engineers, on "Steel; its Properties; its Use in Structures and Heavy Guns,"* gave an exhaustive and lucid treatise on the effects of heat and work on steel. This paper has become classical. Sitting at the feet of such a master, I have endeavored to emphasize the prime importance, in their relation to steel-rail making, of the principles so clearly stated by him.

In a paper on "Steel Rails and Specifications for their Manufacture,"† read at the Buffalo meeting of the Institute in October, 1888, I sought to prove the importance in relation to the wear of rails of their section and the physical treatment of the steel during their manufacture.

Later, in February, 1889, in a paper on "Proposed Rail Sections,"‡ I again urged the same points.

The tremendous increase in the tonnage of railway-traffic and the weight of the rolling stock employed in it having made the use of heavier-sectioned rails imperative and practically universal, and a wonderful development of the iron-ores in the Northwest having taken place, I was led to present to the Institute, in October, 1895, another paper, entitled: "Specifications for Steel Rails of Heavy Sections Manufactured West of the Alleghenies,"§ in which I urged again the paramount importance of work applied at reduced temperatures. It was my privilege to bring this point to the direct personal attention of many railway engineers at the first annual convention of the American Railway Engineering and Maintenance of Way Association, March 15, 1900.||

I urged this in the discussions of the American Society of Civil Engineers during the deliberations which resulted in the adoption of the Report of its Committee on Standard Rail Sections,¶ and, again, when I had the honor of presenting to the same society, at its London meeting, my paper on "The Manufacture of Rails in America."**

While venturing to particularize some of the recorded in-

---

* *Trans. Am. Soc. C. E.*, vol. xvi., p. 283.

† *Trans.*, xvii., 226.

‡ *Trans.*, xvii., 778.

§ *Trans.*, xxv., 653.

|| *Proceedings of the Convention*, p. 121.

¶ *Trans. Am. Soc. of C. E.*, vol. xxviii, p. 425.

** *Proc. Am. Soc. of C. E.*, vol. xxvi., p. 752.

stances of my elaborations of the importance of the physical treatment of steel during its manufacture into rails, I do not wish to imply for an instant that others have not also maintained the same position. D. J. Whittemore, F. C. Delano, Thos. H. Johnson, Wm. Sweet, P. H. Dudley and others have written and spoken to the same effect; but as it happened that I was the only one who had been an actual steel-rail maker, it came to pass that my statements received more attention than they probably deserved; and that must be my excuse for referring to them. But mere words never did accomplish anything, and no matter how much or how often any of us wrote and spoke, so long as the rail-makers did not act, unsatisfactory rails continued to be furnished to the railroads.

As the rush of the modern mill and its tremendous productions seemed to preclude the possibility of obtaining rails rolled at lower heats, I advocated trying to obtain from chemical composition that which could not be secured, under the circumstances, from physical treatment; and, hence, I advocated harder steel in proportion to the increase of section. In fact, good results have come from such mixtures; but I have always insisted, and do now insist, that the chemical composition is secondary to the physical treatment of the metal. There have been instances in the experience of many railway engineers where they have obtained excellent service from steel rails, made in the earlier days, whose chemical analyses revealed the fact that they had neither good nor even consistent chemical character. They were high in carbon and low in carbon; high in manganese, and low in that element; high in phosphorus, and higher in phosphorus; and so on. But they all yielded good service.

Early in 1895 the Pioneer Rail Renewing Co. was organized to develop and operate the process of renewing steel rails, which had been invented and patented by E. W. McKenna. He had been, during his whole business life, an operating railroad man, and as such had been impressed by both the tremendous expense attached to the rail part of maintenance of way and the comparatively short service obtained from the majority of rails—not always because they broke or wore out, but because they became so rough that they were unfit for main-track use; or their ends became battered and had to be cut off. This

latter procedure was expensive; and when the rails were put back into service they did not give a good track, both on account of the increased number of joints and because of the mismating of the rails. So long as the roads had branch-lines or sidings laid with iron rails, the rails from the main track could be used to replace the iron ones, for which there was a constant market: but he foresaw that as the sections on the main line increased in weight, and the subsidiary lines were laid with steel heavy enough and good enough for their requirements, the railway companies would be left without a market for the heavy-sectioned worn-out rails. These considerations led to his scheme for renewing rails and restoring them to their original service in main-line tracks.

The Pioneer Co. rented the old North Chicago rail-mill of the Illinois Steel Co.—the mill, by-the-way, in which the first steel rails rolled in America were made. Here rails were renewed on experimental orders from several different roads. It required time to demonstrate by service the success or failure of these rails.

From the first, I had maintained that the renewed rail would wear better than a new one—basing my belief upon its receiving more work, and that at a low temperature. The rails gave such good results that more capital was raised, and the McKenna Steel-Working Co. was organized, which built a new rolling mill at Joliet, Ill. This was followed by another at Kansas City, Mo.; and I believe one is soon to be erected in the vicinity of New York.

Thousands of tons of rails have been renewed and are giving satisfactory service; and I believe the success of the McKenna renewed rail has had more to do with the commercial recognition of the heat-and-work principle than all of our talks and writings. It was an actual demonstration on a scale which could not be ignored.

The officials of great railway companies were restive in their dealings with the rail-makers. Commercial conditions became such that there could not be any question that the rail business yielded profits; therefore, buyers felt free to demand better goods.

Several of the rail-making companies—notably the Illinois Steel Co. and the Carnegie Steel Co.—recognized the inev-

itable, and prepared plans for the alteration of their rail-mills. The latter has carried its plans into execution, and is to-day rolling rails in its modified mill. All is working well; and I have no doubt as to the better quality of their rails so manufactured.

I believe the Cambria Steel Co. has taken steps to equip itself on the same lines; and no doubt others will soon do so.

The Pennsylvania Railroad Co. made it a part of its rail-contracts for this year that the rails must be finished at a low heat. This naturally brought up the question what constituted such a heat, and how it should be determined. Representing, as I do, the Pennsylvania Lines west of Pittsburg in their rail-inspection, I was consulted; and I recommended the use of Lunette pyrometers. This led to a series of heat-observations with such an instrument, the results of which I shall give.

It may be that the Ducretet & Lejeune pyrometer does not give the exact heat-degrees, but from my observations I feel certain that it does yield consistent results. If it does that, it will be all that is required. Mr. Thomas Morrison, General Superintendent of the Carnegie Steel Co.'s Edgar Thomson Works, who planned and executed their mill alterations, thinks that the distance between the hot saws, which is found to yield a rail of the desired length, will be a sufficiently accurate and practical controlling factor as to the heat at which the rail is finished, and I concur with him; but I think also that the Lunette pyrometer will assist, and will always give quick results.

As observed by such an instrument, the heat at which rails of 80 lbs. to the yard were finished under old conditions in most rail-mills averaged 1795° Fahr. In the Edgar Thomson mill, under existing conditions, the following observations were made, and have been followed by many others, on 80-lb. American Soc. section rails, and also on the lighter sections, with similar results:

Temperature of partially formed rails when first placed on cooling table: 1742°; 1772°; 1772°; 1742°; 1772°; 1772°; average, 1762° Fahr.

Temperature of finished rails on leaving the rolls: 1600°; 1600°; 1574°; 1574°; 1574°; 1574°; 1574°; 1600°; average, 1580° Fahr.

The rails remained on the cooling-table about 1 min. 12 sec.;

the longest time observed being 1 min. 20 sec., and the shortest 1 min. 6 sec.

It was found that the saws, to yield an 80-lb. rail 30 ft. long when cold, had to be set quite 1 in. nearer together than under the old practice.

In the Joliet McKenna renewing-mill, I found that the average temperature at which the rails were drawn from the reheating furnaces was 1750° Fahr. As the rails left the finishing rolls their average temperature was 1480° Fahr. It will be noticed that this was lower than the Edgar Thomson average; and I believe, as the difficulties which surround all new manufacturing steps are overcome, the latter works will finish a little cooler. But this can be overdone. If the steel is too cold it will spring the rolls, receive no work on its interior structure, and so be unsatisfactory. While this can be easily understood, theoretically, Mr. Morrison has demonstrated it by actual work.

Messrs. Morrison and Julian Kennedy have united in a patent for the handling of the rails while on the intermediate or cooling-bed, the gist of which covers the placing of the head of one rail against the flange of another, and so on. The head of the outside rail to be first entered in the finishing pass is exposed; but the bottom of its flange is against the head of the next rail. The theory is that, the flange being thinner, its heat will pass off more quickly; that it will thus draw heat from the head of the rail lying against it, and so will remain longer at a temperature sufficiently hot to roll; and that it will thus give more time for the heat to pass off from the head of the rail, which, as stated, lies exposed. When that rail is entered in the finishing rolls, of course the head of the next one, which had been against its flange, becomes exposed, and so on.

I am happy to say the new method of rolling at the Edgar Thomson Mill does not interfere with its large product. In other words, the production is now quite as large as before its introduction; but the wear of the finishing rolls is greater, and it must be harder on the hot saws.

The rails are finished free from scale, and the steel shows more elasticity under the cold-straightening presses. The fracture of the rails is much closer—that is, the grain of the steel is much finer than in rails of the same section rolled

under the old practice. Such metal must offer greater resistance to abrasion.

There are two rail-mills at the Edgar Thomson works. In the older one, rails of light sections are rolled. At the time of my observations of the finishing temperatures of the 80-lb. rails 40-lb. ones were being made on the old mill. The blooms for these were taken indiscriminately from the heats of steel which went into the 80-lb. rails. It was found that the average finishing-temperature of the 40-lb. rails was 1780° Fahr. As the size of the original blooms for both rails was the same, it follows that the light sections received the greater amount of work; but, as stated, the last, or finishing work, was performed at a higher temperature.

I had rails of both sections nicked and broken, and found the grain of the 80-lb. rail to be finer than that of the 40-lb. one. This, to me, is a convincing demonstration of the effect of work applied at low temperatures.

It is with great hesitation that I venture to suggest new rail sections; and perhaps the very fact of my having been not only a member, but the Secretary, of the Committee of the American Society of Civil Engineers on "Standard Rail Sections," whose labors resulted in the recommendation by that Society of what are now the practically recognized American standards,* ought to make me hesitate all the more; but, on the contrary, I think the knowledge gained in that position gives me the necessary courage to re-open the question.

I regard the described rail-rolling practice as a revolution in steel-rail making. As such, it justifies that which would have been unnecessary under other conditions. Now that the makers have modified their rolling-practice, it is but wise for the railway engineers to modify their rail-sections, so as to obtain the best results from such practice, and in doing this, at the same time adopt sections which will be the best for renewing, while adhering to all of the essential features of the sections recommended by the American Society's committee.

Some railway officials may not be prepared to admit that renewing is to be considered; but I venture the assertion that when the time comes for the necessary removal of the heavy

* *Trans. Am. Soc. of C. E.*, vol. xxviii, p. 425.

sections from tracks, renewing of them will force itself upon their favorable consideration. At all events, if we should adopt a section which (1) is the best for the original manufacturer of the rail; (2) will give satisfactory results in service; and (3) is good for renewal, it would seem that we had acted wisely.

The American Society sections, as they are commercially designated, have made their way until they are practically the standard ones of the country. All roads do not use them; but the majority do. Therefore, they should be regarded as the basis on which new sections are to be designed. I would not advocate changing the 80-lb. section, or those below it, but I do think, in view of the coming manufacturing conditions, that the heavier sections can be advantageously altered.

The greater the area of metal in the head of a rail, the longer it will take, while lying on the intermediate table, for the heat to pass off; if sufficient time is not given, the less will be the "fining" effect of the finishing-pass; and the length of time which the rail can remain on the table depends on the temperature of the flange. The thinner it is, the more rapidly will it cool, and hence, as stated, its condition controls.

Therefore, I think it will be well to design new sections for 85-, 90-, 95- and 100-lb. rails on lines adapted to this heat-condition, and which will also be best for renewal into lighter sections.

In American railway-practice, rails are not permitted to remain in main lines until the wear of metal from off the top of their heads has exceeded $\frac{1}{4}$ in. Side- or curve-wear is another matter. Logging-roads, and other usual customers for relaying rails, cannot afford to buy them of such heavy sections. It certainly will not be economy to consign them to the scrap-heap. Renewing them certainly will be true economy; and it can be confidently expected that the rails will be improved by each renewal.

I believe that the existing Committee No. 4, on *Rails* of the Railway Engineering and Maintenance of Way Association, is the proper body to prepare the sections, and hope they will do so.

Concentrating-Tests and Calculations.

BY OTTO F. PFORDTE, RUTHERFORD, N. J.

(Richmond Meeting, February, 1901.)

THE great advance of the last twenty years in the specialization, delicacy and efficiency of ore-concentrating apparatus calls for a finer system of testing both the qualities of ores and the operations of machines in this department. In amalgamation, lixiviation and smelting, the daily employment of physical and chemical tests has been recognized as necessary, and the cost of the necessary laboratories and employees is cheerfully paid. But while much progress has been made in concentration (due, in a large degree, to the study of the subject in our technical schools), it is still too common in actual practice to follow the loose old method of roughly estimating, once for all, that a given ore "concentrates x tons into one," and resting on this assumption so long as that ore continues to be treated, while assays of the tailings from concentration are made from time to time, without exact determination of their quantity.

The first step toward accuracy of control must be a more frequent and precise measurement of the quantity of concentrates from a given operation. This should be expressed in pounds per unit of one ton; and the variations shown in frequent determinations will furnish a constant check upon the character of the ore and the performance of the apparatus. But this is only a part of what should be constantly and systematically done to insure the best work upon a material which must vary continually, even though it come from one mine only.

If, in any mill, appropriate laboratory-tests were made at least once a week, the labor and expense involved would be amply repaid by increased knowledge and control of the current operations.

A small testing-laboratory, provided with a few gold-pans;

vanning-plaques; coarse and fine scales (the former weighing to 2000 grammes and the latter to 50 or 100 grammes, with 5 to 10 mg. indications); a water-trough; a wash-bottle; a water-faucet (if conveniently practicable); a small drying-oven and a set of sizing-screens, would suffice for the ordinary control of mill-work.

For testing new ores, a mortar and pestle and a simple apparatus for fine grinding should be added; and for some tests of special delicacy and complication a small *Spitzlutte* and a testing-jig would be useful. The total cost of the apparatus would be so small, in view of the economic results to be secured, that it would be wise to furnish at the outset all the conveniences likely to be required.

In discussing the use of such a laboratory (in connection with the assay-office, the existence of which is assumed), certain well-known principles must be borne in mind. It is unnecessary to do more than enumerate them.

1. It is commercially impracticable to concentrate any ore without some loss of valuable material. If the concentrates are pure, the loss in the tailings will be so much higher. If the tailings are barren, there will be so much more worthless material in the concentrates, which will consequently be of lower value per ton.

2. Whether a smaller or larger amount of gangue can be economically allowed in the concentrates will depend partly on the ore itself; partly on local conditions, such as cost of labor, freight and smelting; and, finally, on the capacity of the machinery to treat, without over-driving, detrimental to technical efficiency, a given amount of ore daily.

3. Every laboratory-test should always be of the general nature as that of the corresponding operation in practice, but more careful and accurate in degree.

4. The difficulty of concentrating an ore increases directly with the number of substances to be separated, and inversely with the difference between the specific gravity of the lightest of the useful materials to be saved, and that of the heaviest minerals of the useless gangue from which they are to be separated. When these specific gravities are equal, no satisfactory separation can take place.

5. In the tests, as well as in actual practice, sliming is to be

avoided as far as possible by crushing the ores as coarsely as is consistent with the best separation.

6. Assays serve to determine commercial values, but give no exact clue to the "concentrating-character" of an ore, or the operation of the concentrating apparatus. That is to say, the practically perfect or imperfect concentration of an ore is entirely independent of its commercial value.

7. Each concentrating-ore furnishes its own standard of a theoretically perfect concentration; and this standard varies not only for ores from different mines, but also, at different times, for ores from the same mine.

Tests to be Applied in a Concentrating-Mill.

Assuming such a mill to be provided with an assay-office and a testing-laboratory, as proposed above, we may outline the advisable tests as follows:

As convenient, take a daily or weekly pulp-sample; weigh out 2000 grammes; concentrate carefully in the gold-pans or vanning-plaques; dry the resulting concentrates and weigh in grammes. Each gramme of concentrates thus obtained represents one pound per ton of ore.

The weights and assays found by the test should fairly correspond with the actual weights and assays of the concentrates for each ton of ore crushed. The corresponding tailings of the test should also be assayed, and the results should agree fairly with practice.

These tests and assays should be made at regular intervals, and records of them should be either kept in figures or graphically plotted in a continuous broken line, and continually compared with the actual mill-results. This procedure will show the practicable standard of concentration, and detect at once any failure of the mill-apparatus to do its best work for the given conditions.

Moreover, not only these formal tests but also occasional informal daily tests of the tailings should be made, by taking a small but uniform quantity each time, and, without drying or weighing, washing it down in the pan or plaque, and making a mental comparison with previous tests as to the amount of valuable material lost.

Inaccuracies in the operation of the concentrating-machinery

may thus be detected and remedied much more quickly than by the longer and sometimes impracticable process of assay-tests.

Tests to be Applied to New Ores.

A sample may either be pulverized or in larger pieces. In the first case, weigh out 2000 grammes or a proportional quantity, according to the size of the sample; concentrate carefully in pan and plaque; and note all the constituents of ore and gangue, using a magnifying-glass if necessary. Dry and weigh the concentrates. Each gramme (or proportional part) represents one pound per ton. Assay the pulp, concentrates and tailings to obtain data for calculations. Due account of the slimes should be taken, as the sample may have been ground unnecessarily fine. In case of a massive sample, inspect, and then crush, screening frequently through a 30- to 40-mesh screen, to avoid sliming as far as possible, and proceed as stated above, not omitting inspection on the vanning-plaque, where some substance may appear which escaped detection in the massive piece. In cases where the valuable mineral is very coarse, and suitable for jig-concentration, employ coarse crushing, using, say, from 8- to 20-mesh screens. Separate the coarse from the fine material on a screen of about 30-mesh per inch; treat the former by jigging, and the latter by pan or vanning-plaque; dry, weigh and assay the results separately. The assays of the tailings should fairly agree. The jig-tailings may be a little higher than the rest, for which the ore amply compensates in practice by the larger amount crushed and the decreased tendency to sliming.

This operation will also give a fair idea of the screen-size best adapted for jig-work, as it is desirable, in the great majority of cases, to avoid re-crushing the jig-tailings. Incidentally, assays may also be made of the various selected pure mineral constituents of the ore, to ascertain which of them carry the chief values.

Such tests on new ores are, however, not intended to replace the customary mill-runs; but merely as preliminary inquiries, reaching quick and fairly accurate results, which may render unnecessary the making of expensive mill-tests on unknown ores.

When the preliminary tests have given favorable results, it

is very desirable, in fact essential, to make a trial-run of several tons with the proper mill-machinery before incurring further expenses.

Calculations upon Concentrating-Ores.

In calculating the concentrating-properties of an ore, it must be remembered, first, that the total metallic contents of an ore, or of its products in concentrates and tailings, are entirely independent of the degree to which concentration is carried; secondly, that the assay-value of the concentrates, in perfect work, increases in proportion as the concentration proceeds, until finally, when all metallic and barren materials have been separated, further mechanical concentration ceases. Therefore, when the assay and ratio of a concentrating-ore are given, the amount and assay of the concentrates are readily obtained.

To use a simple illustration: let us assume a perfect concentration of an ore assaying 12 oz. of Ag per ton, and 3 per cent. of Pb and 2 per cent. of Cu (which corresponds to 12 oz. Ag, 60 lbs. of Pb, and 40 lbs. of Cu per ton). Let one ton of this concentrate to 275 lbs. Then the concentration is 2000 to 275, or 7.27 tons into 1, which is used as a factor for multiplying the results of the ore-assays to obtain the corresponding theoretical assays of the concentrates. In this case it is found that 7.27 times the assay-results of the ore given for the concentrates equal 87.24 oz. Ag per ton, and 21.81 per cent. Pb, and 14.54 per cent. of Cu, assuming that all the metal contained in the original ore is collected in the concentrates.

However, as such a perfect concentration is impossible, a practicable standard must be established. This is done by careful concentrating-tests, in which the unavoidable loss depending on the nature of the ore is determined. Suppose that, in the last example, this loss in the tailings has been found to be one-tenth of the assay-value of each mineral constituent, although the concentrating-ratio remains the same, as the lost mineral has been replaced by gangue. Of course, the percentage of loss of the various minerals is not really uniform, so that for each metal this loss must be determined separately. For simplicity only, a uniform loss of one-tenth is here adopted.

By difference it is found that 10.8 oz. of Ag, 54 lbs. of Pb and 36 lbs. of Cu would be available for extraction if an

entire ton of tailings, containing 1.2 oz. of Ag, 0.3 per cent. of Pb, and 0.2 per cent. of Cu had been lost. But as only $\frac{2000 - 275}{2000}$ tons were lost, this figure becomes a factor for the Ag, Pb, and Cu of the tailings, reducing the actual losses to 1.04 oz. of Ag, 5.18 lbs. of Pb, and 3.45 lbs. of Cu, which, subtracted from the contents of the ore, will leave 10.96 oz. of Ag, 54.82 lbs. of Pb, and 36.55 lbs. of Cu as the available mineral in the ore. From these figures the percentage of extraction is readily obtained.

The variations in concentrating-ores are infinite; but, by the method sketched above, a practicable standard can readily be established for each individual ore, which may be considered as constant, within a reasonable limit of time, for ores from the same mine.

The Forecast of Chemical Reactions from the Algebraic Signs of the Quantities of Heat Liberated.

BY PROF. H. LE CHATELIER, COLLEGE OF FRANCE, PARIS, FRANCE.

(Richmond Meeting, February, 1901.)

AN evident connection exists between chemical and calorific phenomena: the most important of our sources of heat, the combustion of coal, is nothing else than a chemical reaction.

Not satisfied with this indefinite statement, investigators have attempted to establish a more precise correlation between these two orders of phenomena, and have questioned whether there be not a necessary connection between the possibility of a chemical reaction and the algebraic sign of the quantity of heat which it would call into play (*i.e.*, liberate or absorb).

This question possesses the highest interest for metallurgical chemists. But the study of it by experimental methods only could not completely elucidate it. To arrive at a definite solution, it was necessary to appeal to a science much more general than chemistry,—namely, that of energetics, which embraces all the physical sciences. We can place absolute confidence in its conclusions, because they rest upon a proposition which can scarcely be denied, namely, the impossibility of

creating energy from nothing; and because, in directions most widely different, these conclusions have always been found ultimately to conform with the results of experiment. Even one who refuses on principle to trust to theory, reserving his confidence for the verdict of experiment only, must at least feel bound to examine with critical severity experiments which, at first view, seem to contradict a theory so solidly founded as this. And deductions, more or less remote, though based on experiment, cannot be urged as more trustworthy than the theory, because such deductions are themselves but theories, and this theory is itself a deduction.

Do All Chemical Reactions Liberate Heat?

At first glance, the superficial observer would reply in the affirmative; but the application of precise calorimetric methods reveals numerous exceptions.

Energetics informs us that two opposite reactions—for example, the combination of carbonic acid with lime and the decomposition of carbonate of lime—call into play equal quantities of heat of opposite algebraic signs. There exist, therefore, two equal groups of chemical reactions, absorbing and liberating heat respectively.

Are the Chemical Reactions which Liberate Heat the Only Ones Directly Produced?

Since there are equal numbers of reactions respectively absorbing and liberating heat, and since, nevertheless, a large majority of those which we observe liberate heat, we may infer that the latter reactions are more easily produced.

It should be added that on this subject we possess more or less precise information for ordinary temperatures only. But there is no rigorous law, numerous reactions being accompanied with absorption of heat. The decomposition of carbonate of lime in the manufacture of lime, the reduction of the oxide of zinc by carbon, and especially the formation of carbonic oxide by the reaction of carbonic acid upon carbon, are instances.

Regarding this question, energetics informs us that at very low temperatures, such as the absolute zero (—273° C.), all the reactions possible at such temperatures directly liberate heat;

whereas, at very high temperatures, the possible reactions which absorb heat become more and more numerous. In other words, the reactions are completely reversed by the change in temperature-conditions. We may infer that the conditions of ordinary temperatures, under which the majority of observed reactions liberate heat, approach more the conditions at the absolute zero than they do those of indefinitely elevated temperatures. But we cannot affirm, *à priori*, that this is the case in the neighborhood of the fusing-point of wrought-iron (say, 1550° C.).

Is there a Law Permitting the Forecast of the Algebraic Sign of Chemical Reactions?

Energetics indicates this law: that, of all the reactions which can take place among the substances present in a given case, that particular reaction tends to take place which will develop the greatest amount of exterior work. But to determine all the available work from any phenomenon, and especially from a chemical reaction, the reaction must be produced by a process which is completely reversible. Now it is extremely difficult to produce a chemical reaction satisfying these conditions; and, moreover, we almost never have the means of knowing the total available energy of a reaction. From a practical point of view, therefore, the value of this law seems to be illusory.

Is there a Relation between Available Energy and the Liberated Heat of a Reaction?

It is often admitted, through a false interpretation of the principle of the conservation of energy, that the two quantities, heat and work, are in all cases equivalent; so that, dividing the number of calories of heat liberated by a reaction by 425, we obtain the number of kilogram-meters of work which that reaction, properly utilized, would furnish. This is extremely inaccurate. The principle of energetics, in its strict and general form, may be stated thus:

If a given system, in passing from a given initial state to a final state, determined with equal precision, performs, in one case, a certain amount of exterior work, and in another case no exterior work, the quantity of heat liberated will be greater

in the second case than in the first, and the difference between these two quantities will be the equivalent of the work performed in the first case. In other words, W_1 being the said work in kilogram-meters and Q_1 and Q_2 the quantities, in calories, of heat liberated in the two cases,

$$425\ W_1 = Q_2 - Q_1.$$

If the phenomenon under consideration be purely mechanical, like the falling of a heavy body, and if, furthermore, the first change of system be strictly reversible, no sensible heat will be liberated in the first case supposed, and the work performed in that case will be equal to the heat liberated in the second. The habit of reasoning from such simple mechanical processes has led to an erroneous simplification of the statement of the principle of equivalence.

In the case of chemical phenomena it is seldom that a reversible transformation can be effected. Yet this can be done with certain electric cells, like the Daniell cell, by which electricity externally furnished may be transformed into work. In a second operation, the copper of the sulphate can be precipitated by zinc without producing electricity or work as a result. It is easy to keep the cell, during these two operations, in a calorimeter which will keep it at a constant temperature by taking or adding heat, as the case may be. Experience shows that the net quantity of heat liberated or absorbed in the reversible operation is very small indeed, but never zero, as the theory of perfect equivalence would require. This principle must therefore be applied in a broad and general sense only.

Returning now to the law of energetics underlying the production of chemical reactions, according to which, the reaction which tends to occur is that which corresponds to the possibility of producing the maximum of exterior work, we may, with the aid of the principle of equivalence, re-state it as follows:

The reaction tending to occur is that in which the difference is greatest between the heat of reaction without exterior work (that is, the heat of ordinary reaction, L) and the heat involved in the reversible operation which corresponds to the production of the maximum of possible work.

The possibility of a reaction depends therefore upon the difference, $L - Q_2$, and not simply upon the heat of reaction, L.

But if the fact, observed in the case of the electric cell, is general—in other words, if Q_2 is always very small—it will be L, in the majority of cases, which will give its sign to the difference. Thus it appears that, at the ordinary temperature, or whenever L is great enough, the reaction occurs in the direction of the liberation of heat. But it would be quite imprudent to extend this generalization to temperatures above the ordinary range.

Energetics permits us to express in another form this difference in the quantities of heat, namely:

$$L - Q_2 = L - S\,(273 + t),$$

in which S is the so-called variation of the *entropy*, a physical quantity, which we do not know how to measure directly. But some facts seem to indicate:

1. That S varies but slightly with the temperature for one and the same reaction, and, indeed, not at all in reactions between solid bodies.

2. That its value is smaller in proportion as bodies transformed, the one into the other, are physically and chemically similar. In the phenomena of substitution and of double decomposition between similar compounds, this value is practically *nil*.

If these indications are correct, it follows that the term $S\,(273 + t)$ increases indefinitely with the temperature t, and consequently that, with increasing temperature, the sign of the difference $L - Q_2$ will be less and less likely to be that of its first term, L. But the similarity of the two signs will be maintained up to higher temperatures, in proportion to the mutual similarity of the bodies involved in the reactions.

We may inquire how far these conclusions agree with known facts. Let us take first, for example, the reactions between carbon, carbon monoxide and carbon dioxide. Of the two inverse reactions $2CO = C + CO_2$, and $C + CO_2 = 2CO$, the first liberates heat and the second absorbs it. The bodies in reaction are quite dissimilar in chemical structure, and therefore the variation of entropy will be relatively great. But the heat of reaction is itself important.

At low temperatures (below 500° C.) the difference $L - Q_2$

has the same sign as L, since the reaction which takes place at the top of an iron blast-furnace is the dissociation of the oxide of carbon, which liberates heat. At high temperatures, as in the hearth of a blast-furnace, the inverse reaction takes place, with the absorption of heat; consequently the sign of the difference $L - Q_2$ must change; Q_2 has become larger than L.

On the other hand, we may examine the reaction of manganese upon the oxide of iron, in the last addition of the Bessemer process:

$$Mn + FeO = MnO + Fe.$$

This reaction liberates only a small amount of heat, and yet it still occurs at these high temperatures; its direction is not reversed as in the case of the oxide of carbon, because the bodies mutually transformed are absolutely similar—the manganese with the iron, and the two oxides with each other. Obviously the change of entropy should be *nil*, and therefore the second term of the difference

$$Q_2 - S\,(273 + t)$$

remains very small.

In the reduction of iron oxide by aluminum or silicon, the compounds which exchange oxygen are very different, and no certain forecast can be made. It is not surprising, however, that aluminum continues to reduce the oxide of iron, by means of its enormous heat of oxidation. The temperature of 1500° C. does not suffice to give preponderance to the second term of the difference in the above equation.

In summing up, we may say that the agreement between the direction of a chemical reaction and the positive sign of the heat of reaction is the more frequent:

1. The lower the temperature;
2. The more similar the substances replacing one another; and
3. The greater the heat of reaction.

So far as the metallurgy of iron is concerned, the concordance here indicated as to the forecast of chemical reactions must be accepted with a certain proportion of skepticism.

The History and Conditions of Mining in the Richmond Coal-Basin, Virginia.*

BY J. B. WOODWORTH, F.G.S.A., CAMBRIDGE, MASS.

(Richmond Meeting, February, 1901.)

THE main facts in the history of the development ot this field of Triassic coals have been already set before the Institute in the papers of Mr. Oswald J. Heinrich, a former member of the Institute and the superintendent of the mines at Midlothian.† From these and other references to the field, it appears that coal was known to exist here as early as 1701; for on the 10th of May that year Colonel Byrd reported to the Colonial Council of Virginia the discovery of coal. Coal was mined from 1770 to 1780; but the amount shipped is unknown. It was much used in Richmond at this early date for grate-fires. In 1789 shipments were made to northern ports. During the first half of the century just passed, mining operations attained in this field their greatest development, the number and extent of the collieries and the tonnage of coal raised per annum being greater for that period than for any similar period since. The maximum annual output exceeded 100,000 tons, while in two years only since the Civil War has the amount of coal raised exceeded 50,000 tons.

This field covers about 150 sq. m. Its outline and the position of the strata in which the coal-outcrops occur are shown on the accompanying map, reproduced from the latest survey by the U. S. Geological Survey. Mining has been carried on along the margins of the area, often in the primitive manner in vogue at the beginning of operations, by means of shafts and slopes, usually too small in cross-section to permit the proper working of the beds. Most of the output has been won from

---

* Published by permission of the Director of the U. S. Geological Survey.

† Several papers, including sections and plans which may prove useful to those interested in the development of this field, are referred to in an appended bibliographic list.

the eastern margin, where the beds were encountered either in detached small basins with a synclinal cross-section, or on the margin of the main basin, where the coal-bearing beds dip westward at a slightly variable angle (usually about 25°, but locally much smaller). The depth of the central part of the basin assuredly exceeds 2500 ft.

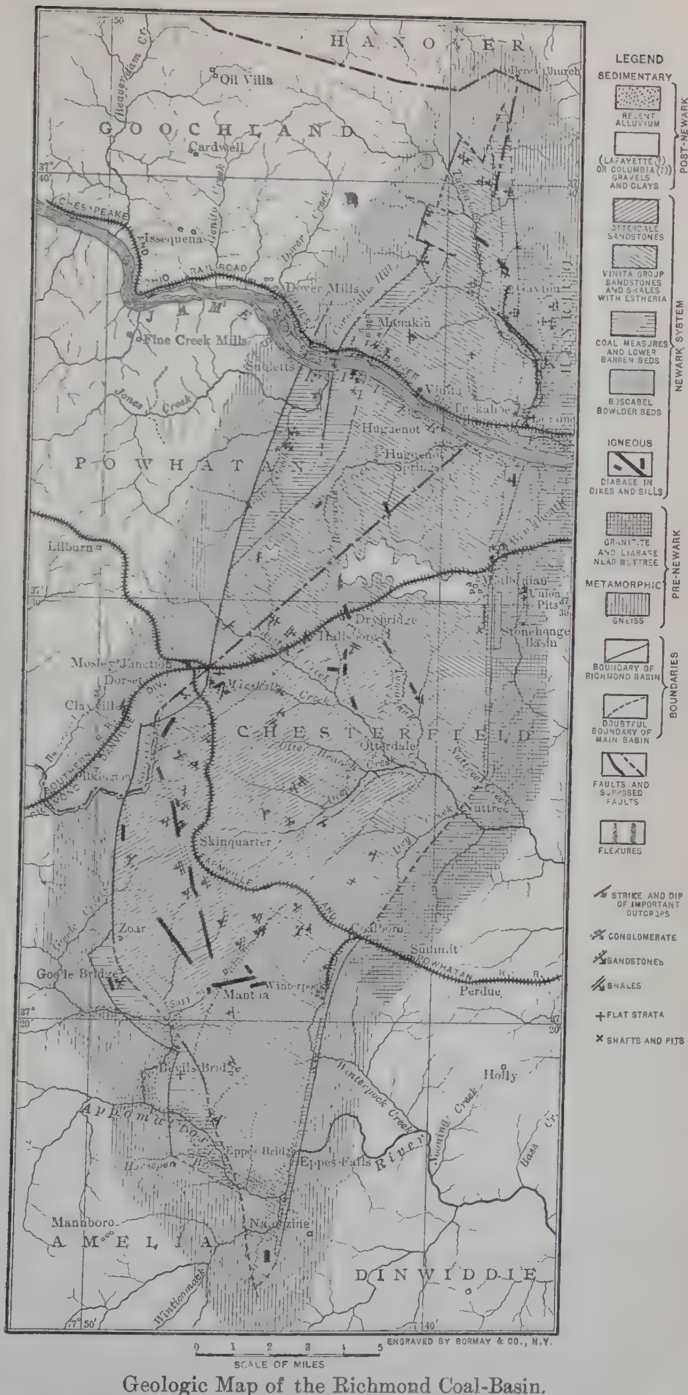
The conditions of mining, as affected by the geological structure, are somewhat peculiar. The following outline of this structure, taken mainly from a report by Prof. N. S. Shaler and the writer, may complement the study of the map, Fig. 1, and the section, Fig. 2.

The coal-bearing strata occupy a basin which widens and deepens from N. to S. to a point near the S. end, where it narrows again. Except in a narrow prong on the E. side, the depth in the S. part is probably greater than in the middle of the field. Along the E. margin the beds, as above stated, dip about 25° inward and westward; but the angle is smaller N. of the James river. The slopes driven down the dip on this side of the basin, particularly in the south, at Clover Hill, or Winterpock, as the place is now known, have encountered at intervals low anticlinal bucklings of the coal-beds, between which the coal is usually found continuing its dip in about the same plane. Over these ridges, the coal is usually pinched, crushed or entirely wanting. As yet none of the workings have extended beyond the marginal inclined beds into the section which underlies the nearly flat beds of the central portion of the field.

On the western margin operations have been much less extensive, and the strata are evidently more disturbed. A glance at the map in the vicinity of the James river will show the existence of a long tilted block of the underlying gneiss projecting into the coal-field, giving indubitable evidence of the faulting which characterizes this side of the basin. Everywhere on this side the surface exposures point to a considerable downthrow of the beds. The absence of the coal-outcrop near Mosley Junction is thus partly explained as due to this downthrow of the beds against the western wall of the basin.

The central portion of the basin in the northern part of the field is frequently flat at the surface, but with lines of flexed strata bent down towards the west, showing that the formation

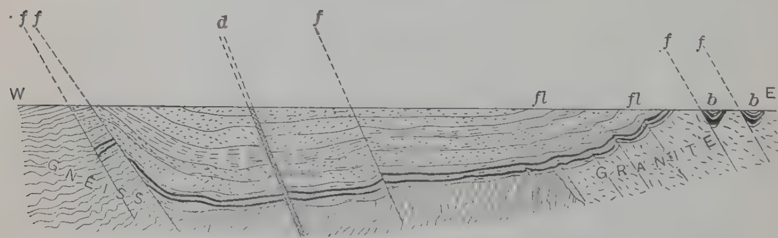
FIG. 1.



Geologic Map of the Richmond Coal-Basin.
Prepared for the U. S. Geol. Survey, by J. B. Woodworth. (From the 19th Ann. Rep. of the Director. N. S. Shaler, Geologist in Charge.)

as a whole deepens in this direction until the beds are brought up against the western margin by dragging on the fault on that side. If the evidence from the margins can be relied upon, it may be assumed that the coal-beds near the base, in the central part of the field, will be found to be more disturbed than the uppermost beds. All the structures in the area point to the conclusion that the dislocation of the beds depends upon fractures and disturbances originating in the underlying granite and gneiss; and that these movements were partly taken up in the overlying flexible beds by flexures and folds—the fractures dying out upwards, so that in the central part of the basin, where the strata are now thickest, few faults reach the surface. The existence of flexed beds in that situation is therefore to be regarded as an indication of increasing dislocation and disturb-

FIG. 2.



Geologic Section of Richmond Coal-Basin.
f, *f*, Faults; *fl*, *fl*, Folds; *d*, Dike; *b*, *b*, Isolated basins.

ance of the lower beds as one approaches the crystalline basement of the area.

These dislocations at the foundation, finding little or no expression at the surface, make the conditions of mining much more uncertain here than in a region of normal folding, such as the Pennsylvania field.

In the southern part of the field, almost continuous westerly dips prevail close up to the western margin, where a narrow block of sandstones rests upon the gneiss, in essentially horizontal position, W. of the apparent main fault. Other faults may exist; but they have not been detected. It is probable that in this portion of the field the depth of the basin is at a maximum, probably 3000 ft. or more.

Dikes and sills of diabase ("whin" or trap) intersect and follow the coal-beds—usually one bed of coal along the east-

ern margin having been thus converted into "natural coke." There is reason for believing that the coking of certain beds in this field will be encountered well under the basin towards the W. side, near which large dikes reach the surface. The outcrops of these dikes are shown on the map, Fig. 1. Many other dikes and sills probably exist; but the deep decay of the surface rock makes it difficult to detect them. Sills of variable thickness, not shown on the map, have also been encountered on the E. margin, in mines now closed. These igneous intrusions are normally black and crystalline; but where the igneous rock has come into contact with the coal and coked it, the gases given off in the process, reacting on the rock itself, have altered it to a greyish-white softened mass, resembling clay. In the approach of the coke-beds to such rock, the coke invariably assumes a prismatic habit, perpendicular to the walls of the intrusive mass. The detached basins on the E. margin, long since worked out, were apparently free from the coke-making sills, although these rocks occur in the coal-beds on the adjacent flank of the main basin. The sills have followed the coal-beds as the path of least resistance; but they have evidently overshot those local basins of coal which were much depressed below the general level, along which the intrusion took place.

Very little information has been recorded concerning the old workings in the basin. The appended list of publications gives the more important references. The borings made along the eastern margin, with the exception of that in the Sinking shaft near Midlothian, have not been recorded.

From letters received since this paper was read at the Richmond meeting of the Institute, it appears that the following notes on the conditions likely to be encountered in testing the ground by borings will be useful to prospectors in this field.

1. From prospecting in this field, except along the margins for a distance of about half a mile from the granite and the gneiss, little is to be learned, other than the geological position of the strata which belong in the thick section overlying the coal-bearing horizon. One or two thin unworkable coal-seams have been reported in these upper beds; and a bed of clay containing fragments of lignite has been encountered in the middle of the area.

Prospecting in the central part of the field is useful to determine the existence of dikes, faults, and flexures, all of which may affect the underlying coals; but, seemingly, no other purpose can be served by it. In selecting sites for boring or shafts, the observed faults, flexures and thicker dikes of igneous rock should be avoided; but it is not in any case known definitely where these structures intersect the coal-beds, since the faults, dikes and flexures apparently do not extend vertically downward from the surface. If the observed faults about the western margin be taken as guides, it is to be expected that the planes of these disturbances in the basin dip steeply eastward. It would appear, therefore, that bore-holes or shafts should be sunk near the western rather than on or near the eastern side of a fault, flexure, or dike seen at the surface. The diagram, Fig. 2, will make this point clear. On the other hand, it is tolerably certain that, except along the western margin, the coal will be found at a somewhat greater depth on the western than on the eastern side of a fault or flexure.

2. There are numerous beds of black shale in the upper part of the section, as in the coal-bearing horizon, which are independent of the coal-making conditions. This is particularly true of the shales crowded with the small impressions of the crustacean bivalve, *Estheria*. Such shales should not be regarded as indicative of the proximity of the coal-beds. In fact, in carrying down test-holes, little reliance can be placed on the evidence from strata passed through, until the coal is reached. The same kind of sediment was deposited over and over again in the Richmond area. It can only be said that sandstones prevail towards the top, above the coal-bearing series, and that shales prevail over sandstones in the lower coal-bearing section. At present, the rule for boring must be "To the coal or the granite!"—a local rendering for "Pike's Peak or Bust!" Only, the arkose or granite-like sandstones which sometimes occur high above the basement should not be mistaken for the floor itself, leading to the abandonment of the boring before the actual coal-horizon has been reached.

3. The drill-core should be watched, to detect any change in the dip of the beds. Experience shows that, even when starting at the surface with horizontal strata, inclined beds shown by the banding of shales, or the contact of sandstone with

shales, brought up in the drill core, may be encountered at moderate depths, below which flat beds may again be penetrated. Such changes of attitude indicate the existence of a flexure like that shown at *fl* in Fig. 2. If the outcrop of this flexure on the surface can be determined, then, with the aid of the data from a bore-hole, a plotting of the dip of its plane can be obtained, and the probable extension of the flexure to the base of the basin may be determined, thus affording an indication of the existence and position of a fault or dislocation in the basement.

4. If thinned- or pinched-out and slickensided coals be encountered, it should be remembered that such occurrences are found along the eastern margin, and that, E. and W. of such disturbed axes, coal has been found in depressed pockets in the greatest thickness known in the area. Such deeper pockets on the eastern margin have been found to descend as much as 600 ft., or more, below the general level of the floor in which they are sunk.

5. Lastly, it is clear that the coal-beds lie near the base of the Triassic section; but it has not yet been proved that they are either persistent or uniform in thickness throughout the area. The remarkable variations in thickness on the eastern margin are associated with compressive movements in the beds.

List of Publications.

Oswald J. Heinrich, "The Midlothian Colliery," etc. *Trans.*, i., 346, and iv., 308; "An Account of an Explosion of Fire-Damp at the Midlothian Colliery," etc., *Trans.*, v., 148; "The Mesozoic Formation in Virginia," *Trans.*, vi., 227. (The last-named paper, published in 1878, gives an account of the Richmond coal-field, and sections at the old Midlothian mine and at Carbon Hill.)

W. B. Rogers, "Reprint of the Geology of the Virginias," edited by J. Hotchkiss. D. Appleton & Co., New York, 1884. (This volume gives analyses of coals, etc.)

William Clifford, "The Richmond Coal-Field, Virginia," *Proc. of Manchester Geol. Soc.* (England), Vol. xix., 1887. (Important to the mining engineer; but this author's conclusions concerning the thinning of the coal-beds have not been confirmed by later observers.)

I. C. Russell, "Correlation Papers—The Newark System," *U. S. Geol. Surv., Bull.* 85, Washington, 1892. (This bulletin gives a bibliography of the Richmond area.)

N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," *19th Ann. Rep. U. S. Geol. Surv.*, Part II., pp. 385–519, Washington, 1889. (This report contains geological map, cross-sections of the coal-field, reproductions of Clifford's maps and sections of abandoned fields, and a discussion of the structure of the basin.)

See also the forthcoming report on "Triassic Coals" in the *Annual Report of the Director of the U. S. Geol. Survey* for the fiscal year 1900–1901.

A Rapid Assay for Silver and Gold in Metallic Copper.

BY GEO. L. HEATH, SOUTH LAKE LINDEN, MICH.

(Richmond Meeting, February, 1901.)

Under the above title it is desired to bring to the attention of assayers a short-cut method which has been perfected by Mr. A. S. Warren, of Buffalo, and the writer; has been used several years at three "Lake copper" refineries in occasional alternation with the regular "combination," or "wet and fire," assay; and has proved more rapid, and rather more accurate than the latter on all refined copper—namely, the direct cupellation of the silver chloride (+gold) precipitate, without scorification.

No claim of priority is made for this direct method, as it has suggested itself to many others, and was mentioned by Mr. Warren in the symposium of assayers' results brought together in 1895 by the Secretary,* after the plan and suggestions of Dr. A. R. Ledoux.†

Lately, this important subject of assaying copper-materials seems to have been re-opened for discussion.

The shortening of time by the direct method is so considerable (nearly 20 minutes on a batch)—to say nothing of the saving

* *Trans.*, xxv. (1895), 250.

† *Trans.*, xxiv. (1894), 575.

of material and the confinement of possible errors in regulation of furnace-heat, etc., to one operation instead of two—that it seems strange that this quick process has not received in print, at least, the attention it deserves.

The fact that an occasional attempt to cupel directly the silver chloride showed loss by "spitting" may have led some assayers to conclude that a preliminary scorification was necessary.

The writer proposes to prove, by the tabulated results of experiments:

1. That although some little time may possibly be required to acquire the proper details of manipulation, yet there need be no loss by spitting if the operation is properly conducted.

2. That the amount of lead required is only from one-third to one-half that required for the old method.

3. That direct cupellation of fairly pure silver chloride gives, if anything, a little less loss than the process involving preliminary scorification, and may be used at will, interchangeably with that process, on all metallic copper which does not leave, on solution in nitric acid, too much residue of silica or sulphur. In the writer's experience, it has been necessary to reject very few check-assays fired by cupellation, in the regular work of the office.

4. That a quantity of insoluble antimony oxides containing over 0.1 gramme of metallic antimony may be easily removed, under the reducing conditions provided for by the writer, without any preliminary scorification. A small part slags off, but the greater part seems to be reduced enough to volatilize.

It is generally admitted, not only by assayers, but by buyers and sellers of metal, that the fire-assay for silver is not a strictly scientific and accurate process, but a commercial one, involving a certain loss in precious metals, which we can only strive to keep within narrow limits by proper manipulation. Accordingly, anything which can save a little time and reduce chances for error seems worthy of careful experiment and detailed description.

The investigation here recorded involved a comparison of the losses sustained by weighed samples of pure metallic silver cupelled with lead, with the corresponding losses on silver chloride treated in three ways—namely, by direct cupellation

with the powdered lead; by such direct cupellation in the presence of insoluble oxides of antimony;* and by scorification with 15 grammes of powdered lead and 5 grammes of litharge before cupellation.

The experimental assays were made with three separate quantities of silver (20+, 50+, and 150+ milligrammes respectively). The writer used a sheet of silver foil purchased from dealers, and found by wet assay that it was pure enough for the purpose. Such foil is sometimes not strictly of the same degree of fineness throughout; but only slight variations could result from this under the conditions.

Of the powdered lead, 100 grammes yielded only 0.02 milligramme of silver, which could not affect results. The lead used should be granulated to pass through a sieve of 30 meshes to the linear inch (2.5 centim.).

Method.

The assays were cupelled in batches of four, in a single row, one-fourth to one-half inch (6 to 12 centim.) from the front edge of the muffle of a No. 2 Hoskins gasolene furnace, the position being regulated according to the heat existing at the time. Each single row of four 1.25 in. cupels was planned to contain: (*a*) one sample of metallic silver, as a proof; (*b*) one of silver chloride; (*c*) one of silver chloride with oxides of antimony; and (*d*) one button of lead and silver from the previous scorification of silver chloride.

The loss in the samples *b*, *c* and *d* of any batch may thus be compared with the loss at the same heat in the "proof *a*."

The order of the several cupels in each batch of assays was varied, each line, read horizontally from left to right, representing a row of cupels:

1— 2— 3— 4
6— 5— 8— 7
9—12—10—11
13—14—15—16, etc.

Wet assays of the standard silver (by precipitation as chloride

* A weighed sample of powdered metallic antimony was dropped into the beaker with the silver foil before adding the nitric acid.

—or bromide—and ignition in porcelain crucibles) were also made, to prove that the losses, shown in furnace-work, were not due to any error in solution and precipitation of silver chloride or want of fineness in the silver employed.

Weighed as :	Silver Taken, Grammes.	Found, Grammes.	Error, Grammes.
Chloride, (Factor, 0.7527)	0.04868	0.04855	—0.00013
	0.05221	0.05227	+0.00006
Bromide,	0.04842	0.04820	—0.00022

Mr. Warren says, in a letter, that he has found the use of bromides instead of chlorides, as recommended by Cabell Whitehead,* of great advantage in the wet "mint" assay of silver bullion, shortening the required time nearly one-half.

More details of the method used for direct cupellation of the chloride, as obtained from a solution of copper borings, will be given to indicate the essential points.

When the determination of gold is desired it is filtered off first. The writer recommends the plan adopted by assayer "Q" in the symposium of 1895,† until some better collector is found. He obtained high results on gold, and avoided loss from excess of chlorine, by adding only one drop of solution of chlorides to the nitric acid solution of copper and silver, to collect the gold. The dried filter may then be held in a loop of platinum wire and carefully charred, allowing the half-burned ash to drop into the filter containing the silver-chloride.

Any globule of sulphur might be picked out of the solution before precipitation, burned off, and the residue replaced in solution. The chloride is filtered off on a 7-centim. S. and S. washed filter, No. 589.

A solution of one assay-ton of copper-borings may be filtered and washed in less than ten minutes by using a large-stemmed 2-inch funnel, placing under the filter a platinum cone with very coarse perforations (about 1 mm. in diameter), and keeping the stem full of filtrate.

Portions of 6 grammes of lead are placed on little rectangular pieces of sheet-iron (2.5 by 1.5 in.), with the corners turned up

* *Jour. Anal. and Appl. Chem.*, vol. vi., p. 262 (1892); also, *Eng. and Min. Jour.*, Feb. 26, 1898, p. 250. † *Loc. cit.*

a little at one end, to form a small scoop which can be quickly handled by the cupel tongs.

The filters, *still wet*, are taken from the funnels in order of number, and from 1.5 to 2 grammes of the powdered lead are dusted over the inside. The top of the filter is closed together and the filter folded down upon itself, so that the side of double thickness shall be the outside.

The red-hot cupel is quickly drawn forward and the remainder of the lead spread in it, the folded filter placed in, point down, and the cupel shoved back into the hottest part of the muffle.

The reduction of the silver chloride should be quick, and completed before the outside envelope has been burned off; and the door of the muffle may have to be closed as soon as the cupels are filled.

This description applies to muffles without forced draft. Mr. Warren says that, with natural gas and forced draft, he has thought best to bring cupels forward, outside the furnace, while burning the paper, and then to cover with lead and cupel.

As soon as the lead is hot the cupel may be tipped a trifle, if any little globule of lead is caught just above the edge of the molten bath, and is then brought to the front of the furnace, and the operation finished at low heat with the usual precautions—production of feather-litharge, etc.

Results.

Table I. shows the losses of silver resulting from the separate conditions specified.

Assays made under the same conditions (although at different times) were grouped together in the table, so that the averages might be exhibited.

Bringing together the average losses, under varying conditions, we have the results shown in Table I.

This table contains some figures on silver-loss in cupelling, taken from Table II. in Furman's paper, the tests of Mason and Bowman, and the results of Godshall. The percentage-loss of silver seems to be a trifle less, the larger the silver button; hence only those results could be compared which were the result of tests on the same weights of silver.

TABLE I.—*Losses of Silver in Cupellation, etc.*

Number.	I. Cupelled Direct—Metallic Silver. Silver. Taken.	Found.	Loss.	Loss.	Number.	II. and III. Cupelled as Chloride. II = Without. III = With Sb. Oxides. Silver. Taken.	Found.	Loss.	Loss.	Number.	IV. Silver Chloride, Scorified, then Cupelled. Taken.	Found.	Loss.	Loss.	Wt of Lead Button from Scorification.	Remarks.
	Mg.	Mg.	Mg.	Per cnt.		Mg.	Mg.	Mg.	Per cnt.		Mg.	Mg.	Mg.	Per cnt	Grms.	
1..	51.03	49.84	1.19	2.33	2..	51.10	49.62	1.38	2.70	4..	57.38	54.83	2.55	4.44	3.0	All weights are given in milligrammes of metallic silver.
					3..	54.00	52.92	1.08	2.00							
5..	53.44	52.57	0.87	1.65	6..	52.70	51.43	1.27	2.41	8..	53.61	51.67	1.94	3.62	2.0	
					7..	50.76	49.68	1.08	2.13							
9..	51.90	50.63	1.27	2.45	10..	56.12	54.53	1.59	2.82							
14..	52.95	51.20	1.75	? 3.30	22..	51.15	50.16	0.99	1.93	12..	55.00	51.80	3.20	5.82	2.0	
19..	Lost.				26..	55.01	53.77	1.24	2.25	17..	50.00	46.73	3.27	6.54	1.5	
21..	52.60	51.70	0.90	1.71	30..	53.17	52.14	1.03	1.94	20..	51.18	48.30	2.88	5.62	2.0	III. (*a*) 0.5 gramme metallic antimony placed in beaker with silver before adding the dilute nitric acid, and 1.0 gramme $PbCl_2$ mixed with lead in filter.
25..	51.05	50.13	0.92	1.80		II. Average loss............			2.27		Average loss............			5.21	2.0*	
29..	50.85	50.00	0.85	1.67	13..	19.78	18.72	1.06	5.35	21..	52.03	50.83	1.20	2.31	6.5	
	Excepting No. 14, Average loss.........			1.94	15..	19.94	18.97	0.97	4.87	32..	52.60	51.83	0.77	1.47	6.0	
						II. Average loss............			5.11		Average loss............			1.89		
					16..	53.50	51.90	1.58	2.95							? No. 14, 13, 15: heat a little too high.
					18..	52.47	50.72	1.75	3.33							
					23..	52.15	50.63	1.52	2.91							
					27..	51.40	26.90	Slagged badly and froze.								
					31..	50.97	34.90									
						III. (*a*). Average loss......			3.06							
33..	151.50	149.40	2.10	1.39	34..	152.25	149.98	2.27	1.49	36..	154.08	150.96	3.12	2.02	5.5	III. (*b*) and IV. (*b*) 0.1 gramme antimony placed in beaker.
37..	151.92	150.23	1.69	1.11	38..	152.47	149.50	2.97	1.95	40..	151.39	147.10	4.29	2.83	5.5	
41..	149.98	148.40	1.58	1.06	42..	152.05	149.78	2.27	1.49	48..	154.98	151.08	3.90	2.52	7.0	
45..	151.40	148.65	2.75	1.81		II. Average loss............			1.64	52..	150.30	145.70	4.60	3.06	5.5	
49..	149.67	147.02	2.65	1.77							Average loss.......... ..			2.61		
	Average loss............			1.43	35..	154.87	150.60	4.27	2.76							
					39..	153.67	146.90	6.77	4.40							
					43..	150.44	140.30	10.14	6.74							
						III. (*a*). Average............			4.63							
					46..	152.77	149.40	3.37	2.21	47..	154.28	150.12	4.16	2.69	6.5	
					50..	152.80	149.23	3.57	2.33	51..	151.30	147.00	4.30	2.84	7.0	
						III. (*b*). Average loss......			2.27		IV. (*b*). Average loss......			2.76		

* Scorification pushed to an extreme limit.

TABLE II.—*Average Percentage-Loss of Silver.*

Quantity of Silver in Sample.	Losses. In Cupelling Metal Direct with 6 Grammes Lead.	Losses. In Cupelling Chloride Direct with 6 Grms. Lead.	Losses. In Scorifying Chloride and Cupelling Lead Button.	Weight of Lead Button from Scorification.	Remarks.
Milligrammes.	Per cent.	Per cent.	Per cent.	Grms.	
20	5.11	......	......	......	Heat a little high. Proof lost 3.3 per cent.
50	1.94	2.27	1.89	6.2	
		3.06 (*a*)	5.21	2.0	(*a*) 0.5 gramme of antimony carried through with assay.
150	1.43	1.64	2.61	5.6	(*b*) 0.1 gramme of antimony carried through with assay.
		4.63 (*a*)	......	......	
		2.27 (*b*)	2.76	......	
F. Ag, 150	Ag, 1.54	......	Ag, 2.32	6.+	F. Furman's results, *Trans.*, xxiv., 740.
F. Au, 2.+	Au, 1.47	......	Au, 1.51		
M. about 197	2.19				M. Mason and Bowman's tests, *Journ. Am. Chem. Soc.*, xvi., 313 (1894)—7 tests selected having same weight of silver.
G. 20(*c*)	5.68 to 3.26				G. Godshall's results from cupels in front, taken from his tables, *Trans.*, xxvi., 474–484.
G. 20(*d*)	3.03 to 2.80				
G. 50(*c*)	2.12 to 2.44				
G. 50(*d*)	2.17 to 2.71				
G. 100(*c*)	1.86 to 1.87				(*c*) with 0.25 A.T. lead.
G. 100(*d*)	2.24 to 1.87				(*d*) with 0.5 A.T. lead.

Furman used rather more lead than the others. Mason and Bowman did not give any particulars. The agreement is really very close.

The effect of an excessive quantity of antimony is to increase the losses and form a ring of slag in the cupel, even though the writer dusted some lead chloride into the filter. This salt appeared to assist in the removal of an excessive amount of oxides of antimony. The oxides resulting from 0.1 gramme of this metal are as much as would ordinarily be found even in a casting copper, and there is no difficulty in removing that amount from the silver by direct cupellation of the chloride with 6 grammes of lead, observing the precautions given.

It is our experience that after one acquires the knack or cupelling the chloride precipitate without "spitting," the method rarely fails to show good agreement in check-assays.

As the question of solubility of gold in the nitric-acid solution of copper is another matter, and a special problem not yet satisfactorily solved, it has not been discussed here.

Out of 274 pairs of original check-assays of silver in various Lake coppers, taken consecutively without selection, and fired by two operators, 240 pairs agreed within 0.5 oz., 21 more were within 0.7 oz., and the remainder of 13 within 1 oz., Troy, per ton.

Of the 13 mentioned, it was found that a few of the sample-plates cast from the molten charges were uneven, probably from pouring too cold. Sample-plates 6 in. square and 0.5 in. thick were used to avoid the bad effects of the segregation of silver on cooling—a question which was ably treated, some time ago, by Edward Keller, of Baltimore.

Considering that the direct cupellation of the silver (and gold) chloride precipitate saves time, confines the chances of errors in judgment of temperature, etc., to one operation, and reduces to one-third or one-half the amount of lead required, we recommend that assayers should try this quick assay for refined coppers and anodes, reserving the usual "combination"-method for mattes and crude copper, which leaves so much siliceous residue, etc., that a slagging melt in the scorifier is necessary before cupellation.

Discussion.

A. R. Ledoux, N. Y. City: The short-cut process which has been so carefully tested by Mr. Heath has, of course, suggested itself to nearly all assayers who have determined silver in copper material by the "combination" process. It was tried in my laboratory several years ago, and our results entirely confirm the conclusions of Mr. Heath. Where one is handling refined copper, such as anodes or the Lake product, it is safe to cupel the chloride without preliminary scorification. But on converter-copper, or any impure form of pig, it cannot be employed, for the reason which Mr. Heath states: namely, there is too much sand, sulphur and other insoluble matter in such products.

The Coal-Fields of Northeastern China.

BY NOAH FIELDS DRAKE, TIENTSIN, CHINA.

(Richmond Meeting, February, 1901.)

THIS paper is devoted chiefly to the coal-fields of the western part of the province of Chili and the eastern part of the province of Shansi; but the outline of this belt will give some idea of the extension of the coal-fields over northeastern China.

This part of China is topographically divided into: (1) the mountainous peninsula of eastern Shantung; (2) the coastal plains, extending W. and SW. from the gulf of Pechili; and (3) the mountains and table-lands N. and W. of the coastal plains. The plains extend N. and W. from the gulf to within from 10 to 25 miles of the Great Wall, while their SW. extension covers western Shantung and reaches W. along the Yellow river almost to the southern boundary of Shansi. A line joining the mapped coal-fields, shown in Fig. 1, almost gives the western boundary of the plains; since these areas lie on the border of the plains—except the Tsê Chou field, which is on the table-land, 20 to 25 miles from that border.

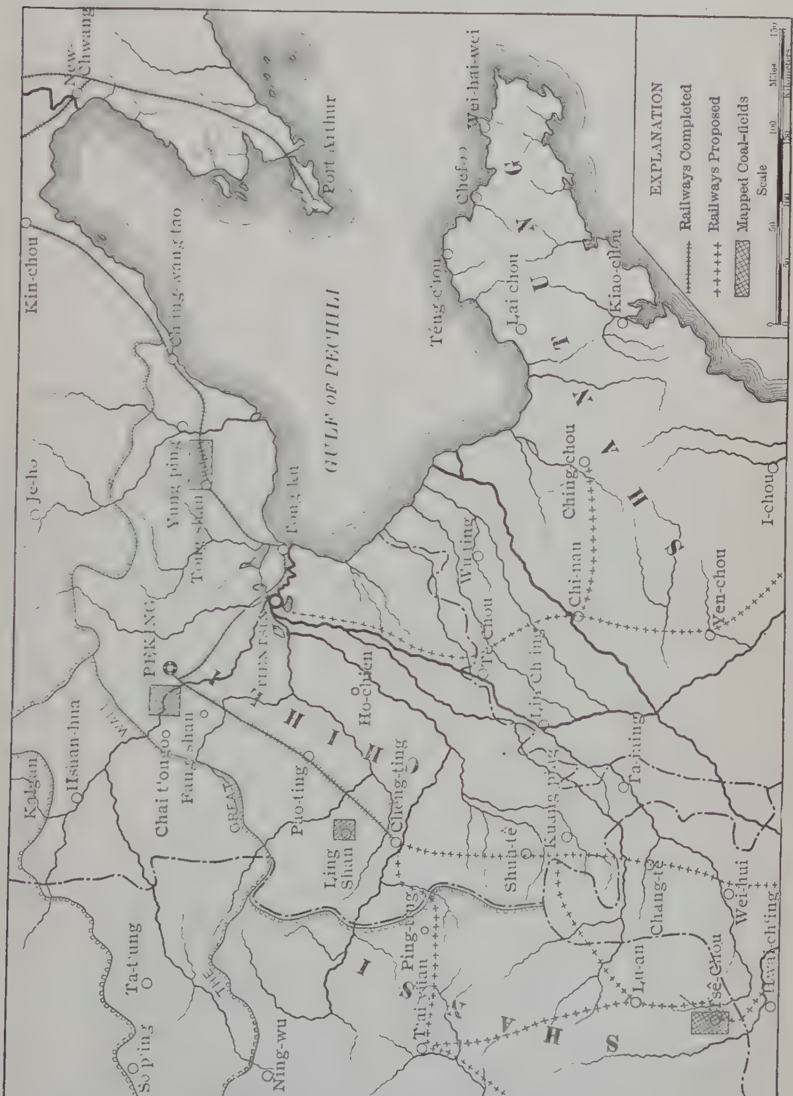
The coal-fields which have been mapped and investigated by the author are shown in Fig. 1. The one at and around Tongshan is known as the K'ai-p'ing coal-field; the one W. of Peking has been called the Wang-p'ing coal-basin; the one SW. of Pao-ting and N. of Chêng-ting may be called the Lingshan coal-field; and the one at and around Tsê Chou is known as the Tsê Chou coal-field.

I. THE K'AI-P'ING COAL-FIELD.

As is shown in Fig. 2, most of this field lies in the coastal plains, and is therefore covered by alluvium and loess, which have buried the older rock-beds, and the more gentle and older topographic outlines, to such an extent that most of the re-

maining hills rise abruptly out of the plains. These hills, with their continuation a few miles to the north of the mapped area, reveal older rock-beds, which have been thrown into large

FIG. 1



Map, Showing the Location of Some of the Coal-Fields of Northeastern China.

folds and planed off by erosion so as to expose a succession of strata, from the coal-bearing shales and sandstones at the top, through from 10,000 to 15,000 ft. of limestones, cherts, sandstones, shales and conglomerates, down to the basal granites.

For present purposes, we shall consider only the upper portion of these older beds, which is illustrated in Fig. 3, and averages about as follows, beginning at the bottom:

	Feet.
A. Limestone, about,	2000
B. Clay shale and shaly sandstone,	100
C. Sandstone,	50
D. Clay shale, shaly sandstone, fire clay and a very little coal,	100
E. Clay, shale, sandstone and coal (these strata contain nearly all of the workable coal-beds),	350
F. Shaly clays, carbonaceous and arenaceous shales, shaly sandstones and a little coal,	250
G. Ferruginous sandstone and iron-ore,	15
H. Clay shales and shaly sandstones,	75
I. Quartz-grit,	20
J. Reddish ferruginous clays, interstratified with occasional beds of rather soft, light yellow sandstone and grit, over	1000

The rock-beds, exclusive of the covering of loess and alluvium, lie in what is apparently one large synclinal fold, with accompanying irregularities of small folds and faults. Some of the larger faulting has, however, resulted in fault-blocks, which lie more or less independent of the main fold. Apparently one such fault-block is that on the W. side of the hills at Tong-shan (see Fig. 2).

The N. side of the synclinal fold can be traced from Tong-shan NE. to a short distance E. of the Tou Ho. It probably continues in that direction: but the older rocks are covered with loess and alluvial as far as Ma-chiakou, where the coal-beds may be traced again 3 or 4 miles further NE. Thence the fold strikes E. for about 5 miles (Line C–D, in Fig. 2, crosses the middle of this course): then SE. for about 2 miles; and then eastward again. About a mile east of Lin-hsi the rock-strata closely associated with the coal-beds are again covered by alluvial deposits; but the further continuation of the synclinal fold is clearly shown by the line of limestone hills formed by the upturned edge of the limestone formation which closely underlies the coal-bearing beds. The hills around Lei-Chuang beautifully show the end of the fold by the spoon-shaped structure of the limestone (see sections on G–H and I–J, Fig. 2). It is probable that coal exists for a large part, if not all, of the distance between Lin-hsi and Lei-Chuang. A part of the coal-beds along this end of the syncline may


LEGEND
Coal-Bearing
Limestone
Loess
Coal Mine
CH'ING SHUI SHAN
Ch'ing Shui Ho
PEI P'O
Ch'ing-shui-chien
Wang-p'ing-Ts'un
Hao-chia-fang
Mêng-wu Ts'un
Hui-yü
HOU SHAN
Liu-li-chü
San-chia-tien
Hsin-fu
HUN HO
Pan-ch'iao
Wang-p'ing-k'ou
CHIU-LUNG SHAN
T'an-fang
Ta-yü
Mên-t'ou-ko
Wên-shui-yü
TIEH P'O
Ch'ao-t'ai
TA-LUNG SHAN
Lin-chia-chuang
Hsi Ts'un
Hsin-fang
Nan Ts'un
Liu-chia-t'an
MA-AN SHAN
Hua-shih-p'ien
Ho-nan
Pei-ch'e-ying
Ch'ui-chia-wu
MAP
OF A PART OF THE
WANG-PING COAL BASIN
BY N. F. DRAKE
Scale
Miles
Kilometers
1900
Bormay & Co., N.Y.

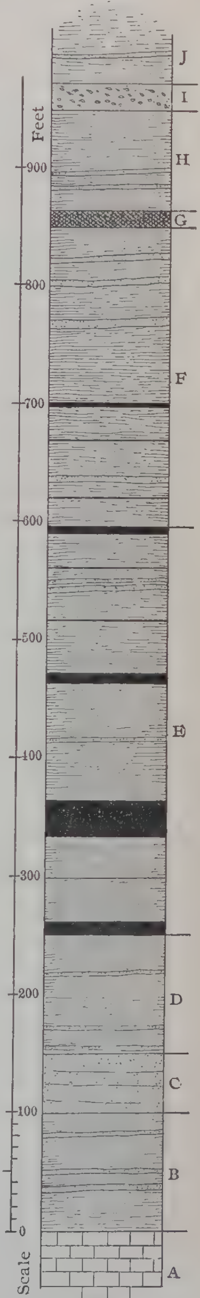
have been eroded away before the deposition of the loess and alluvial deposits; but it is hardly possible that the erosion reached deep enough to carry away the whole of the series.

The coal-mines at Lin-hsi are on the S. side of the fold and near the outcrop of the coal-beds. West of Lin-hsi, the alluvial deposits again cover the older rocks so that the further extension to the westward on this side of the syncline is only conjectural. For a mile or more on either side of the section on C–D, Fig. 2, the strata are slightly overthrown, so that they dip N.

Coal-mining by foreign methods was begun in this district in 1878. Tong King-sing, managing director and originator of the China Merchants' Steam Navigation Company, organized, with the aid of Li Hung-chang, a Chinese company, to mine coal in the K'ai-p'ing coal-field. Mr. R. R. Burnett was appointed chief engineer. Prospecting, by means of bore-holes, was done in 1878; and a shaft was sunk at Tong-shan and coal was raised in 1879. Since that time the mining work has gradually increased.* A colliery was started at Lin-hsi in 1889, and one at Hsi-shan (about one mile northwest of Tong-shan) in 1894. During 1899, about 778,240 tons of coal were mined at Tong-shan, Lin-hsi, and Hsi-shan. Tong-shan furnished about two-thirds of the total. The total amount of coal mined by the Chinese Engineering and Mining Company up to date is about 6,000,000 tons.

The mine-workings at Tong-shan reveal 13 coal-seams, varying in average thickness from a few inches to about 25 ft. A cross-section of these seams is shown in Fig. 4. Beginning

FIG. 3.



Average Section of Strata of K'ai-p'ing Coal-Basin.

* An account of this mine, with illustrations showing methods of mining and apparatus, by Kwong Yung Kwang, engineer at the mine, was published in *Trans.*, xvi., 95 (1887)

at the top, they run, as to thickness and quality, about as follows:*

Seam No.		Feet.
1.	Good coal,	1.5
2.	Good coal,	1.5
3.	Friable and poor coal,	7
4.	About	1
5.	This seam furnishes the best coal that is mined at Tong-shan. The ash averages about 7 per cent. Coal-analysis No. 4, page 505, is that of a piece from this seam. Average thickness about	5
6.		2
7.		2
8.	Poor coal,	8
9. 10.	These lie together usually, and have an average combined thickness of about	25
11.	Good coal, but not worked; thickness about	2
12.	This seam has an average thickness of about	20

If we exclude every seam that does not exceed 2 ft. in thickness we still have an aggregate thickness of coal of about 65 ft.

At Lin-hsi, the coal-seams are, on the whole, somewhat thinner than at Tong-shan. The four larger seams average about 15, 8, 4 and 3 ft. respectively. When I first visited the mines, in the summer of 1898, I measured the thickness of the largest bed at one place, and found it to be about 15 ft. The dip of the coal-beds at Tong-shan averages about 50°, while the dip at Lin-hsi is only from 20° to 25°. At both places, and especially at Tong-shan, the dip is irregular.

All the coal in the K'ai-p'ing field is bituminous and produces a good coke, but varies considerably in quality in different beds and at different localities. Mr. H. C. Hoover, consulting engineer for the mines, has made a minute study of the coals, and proposes to divide them into three classes, as follows:†

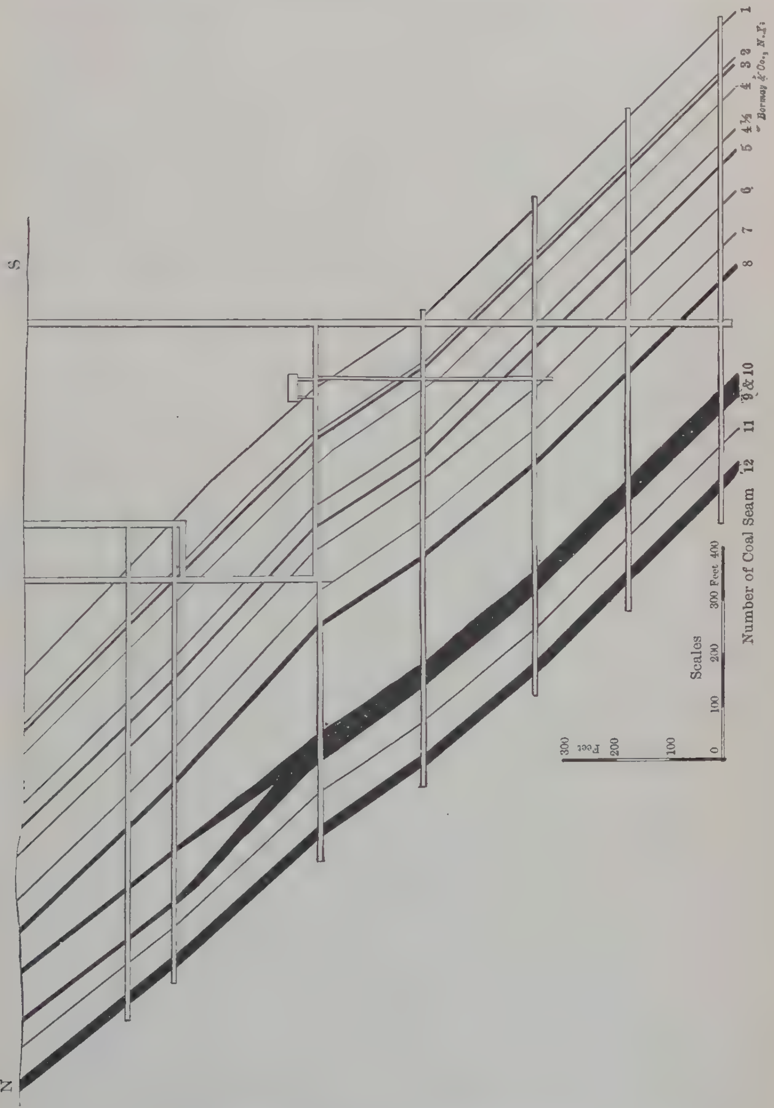
* For a considerable part of the data relative to the average thickness and quality of the coal-seams at Tong-shan and Lin-hsi, I am indebted to C. W. Kinder, former engineer-in-chief of the Tong-shan mines; H. C. Hoover, present consulting engineer for the mines; and Kwong Yung Kwang, engineer of the Lin-hsi colliery.

† Abbreviated from a written communication.

"Class A. This class embraces seam No. 5, and parts of Nos. 9 and 10. Analysis No. 1, page 505, is from average samples of this coal, uncleaned. The seams of this coal yield from 35 to 40 per cent. of lump-coal.

"Class B. This class would comprise the remaining portions of seams Nos. 9,

FIG. 4.



Cross-Section of Coal-Beds and Mine-Workings at Tong-Shan, 1899.

10 and 12, and would form the bulk of the coal at Tong-shan. Analysis No. 2, page 505, represents this class.

"Class C. This class would comprise seams Nos. 3 and 8 at Tong-shan, and Nos. 8 and 9 at Lin-hsi. Analysis No. 3, page 505, is an average one from coals of this class."

II. The Wang-p'ing Coal-Basin.

This name was applied by Pumpelly* to a belt of coal-bearing strata, from 12 to 15 miles wide by more than 30 miles long, which extends due W. from the beginning of the hill-country W. of Peking. The information which he gave concerning the coal-beds consisted mainly of observations concerning individual mines, the extent and correlation of the beds being left for later investigators to determine. His report has served a good purpose as a working basis. The next information of value as to the geology of this region came from Baron von Richthofen,† who did some geologic work there in 1871, classifying and naming the different coal-bearing series, and furnishing important data about most of the coal-beds. Since that time a number of mining engineers have made hasty examinations of the coal; but apparently they have always been unfavorably impressed as to the practicability of profitable coal-mining on a large scale in this field.

The part of the Wang-p'ing coal-basin which was examined by the author is shown in the map, Fig. 5, which begins at the edge of the coastal plains, 7 or 8 miles W. of Peking, and extends from 10 to 20 miles back into the hill-country. This map was made by measuring a base-line one mile in length, triangulating for principal points over the field, and filling in details by rapid sketches. Only a few of the many villages in the field are shown. The limestone hills, however, are almost destitute of villages or cultivated fields. The coal-mines indicated on the map are only those of which underground examinations were made, and constitute but a small part of the numerous mines now worked within this basin.

Almost the whole of this mountainous area is exceedingly rough, being broken into numerous hills and narrow deep cañons, and presenting nearly everywhere steep hill-sides. Where the hills are entirely of limestone, they are so steep and rugged that it is often difficult to find sufficient foothold to climb to the top. The principal hills rise from about 2000 to about 4000 ft. above the level of the plains. The two principal

* *Geological Researches in China, Mongolia and Japan*, by Raphael Pumpelly, p. 10.

† *Letters to the Shanghai Chamber of Commerce*, by Baron von Richthofen, pp. 77–80; and *China*, by Baron von Richthofen, vol. ii., pp. 292–398.


LEGEND
Coal-Bearing
Limestone
Loess
Coal Mine
CH'ING SHUI SHAN
Ch'ing Shui Ho
PEI P'O
Ch'ing-shui-chien
Wang-p'ing-Ts'un
Pan-ch'iao
Wang-p'ing-k'ou
T'an-fang
Hao-chia-fang
Mêng-wu Ts'un
Hui-yu
HOU SHAN
Liu-li-chü
San-chia-tien
Hsiu-tu
HUN HO
CHIU LUNG SHAN
Ta-yü
Wên-shui-yü
Mên-t'ou-ko
TIEH P'O
Ch'ao-t'ai
TA LUNG SHAN
Lin-chia-chuang
Hsi Ts'un
Hsin-fang
Nan Ts'un
Liu-chia-t'an
MA-AN SHAN
Hua-shih-p'ien
Ho-nan
Pei-ch'e-ying
Ch'ui-chia-wu
MAP
OF A PART OF THE
WANG-PING COAL BASIN
BY N. F. DRAKE
Scale
Miles
Kilometers
1900
Bormay & Co., N.Y.

streams, the Hun Ho and Ho-tou-kou Ho, have cut deep and narrow passages through the hills, so that their beds lie but little above the level of the plains.

The rocks of this area are strikingly divided into two groups: one of limestones at the bottom; and one of sandstones, shales, conglomerates and coal-beds at the top. But, upon closer examination, they are found to constitute five groups, as follows: (1) limestones at the bottom; (2) over these, a group of shales and coal-beds 400 or 500 ft. thick; then (3) about 1000 ft. of sandstones; then (4) another group of shales, sandstones and coal-beds, about 500 ft. thick; and (5) above these, the fifth group, which is mainly sandstones.

These groups may be further divided into more or less definite horizons, as shown in Fig. 6, which represents an average section, beginning at the bottom, and comprising:

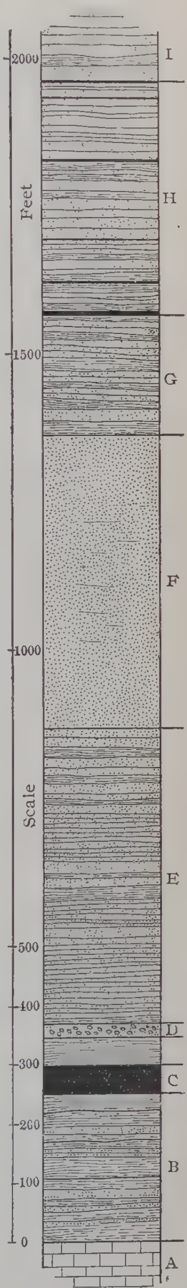
	Feet.
A. Limestone, about	2000
B. Carbonaceous clay shales and a little sandstone, ...	250
C. Coal, ...	35
C to D. Carbonaceous clay shale, ...	50
D. Chert conglomerate and grit, ...	25
E. Principally shaly and thin-bedded sandstone,	500
F. Massive greenish sandstone. This sandstone is so uniform in structure and so hard that, even in huge blocks, it is difficult to tell the direction of the bedding-planes, .	500
G. Shaly sandstones and clay shales, . . .	200
H. Principally sandstones interstratified with thin clay shale strata and some coal, .	400
I. Mainly sandstones. (Thickness not estimated.)	

The top of the limestone A and the conglomerate-bed D are the best guides in locating the big coal-bed C.

Geologic Structure.

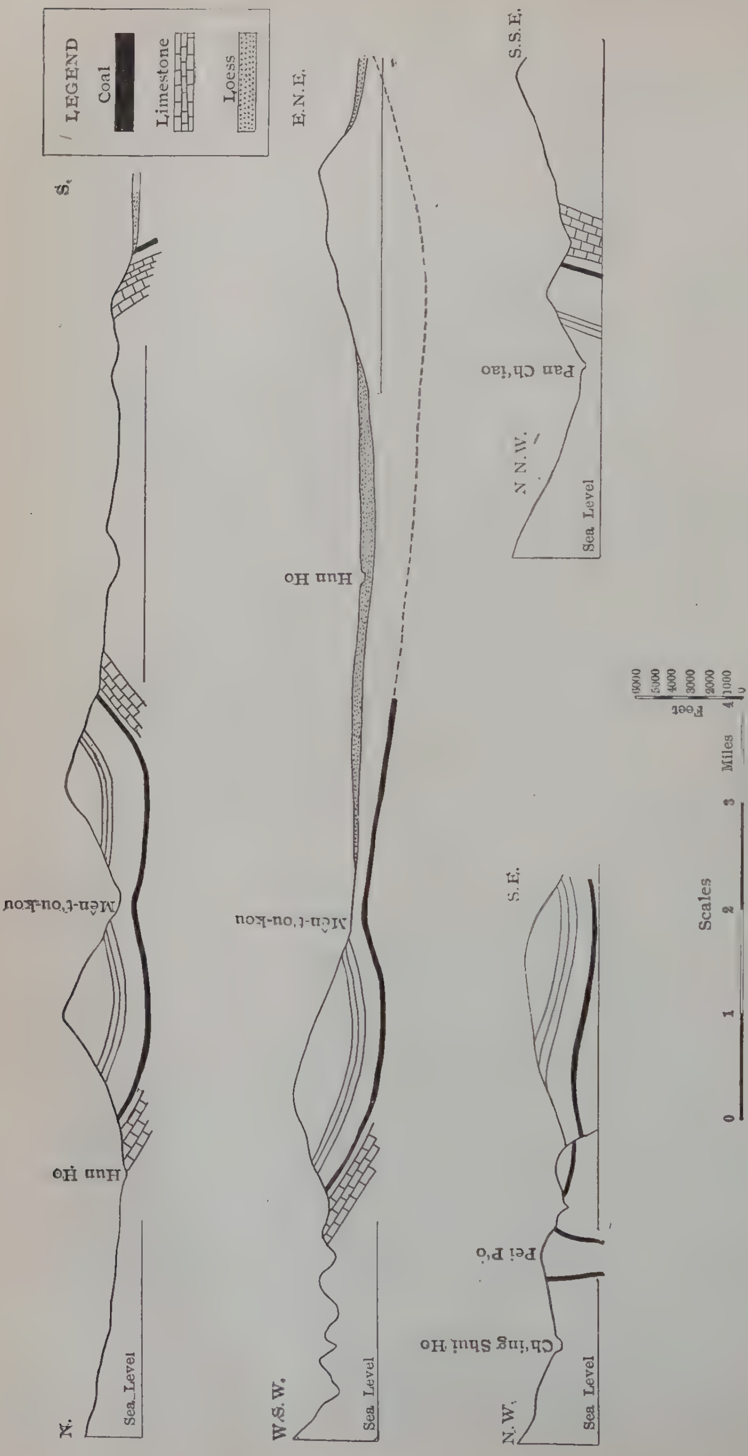
Figs. 5 and 7 illustrate the broader structural features. This is the meeting-ground

FIG. 6.



Average Section of Strata of Wang-p'ing Coal-Basin.

FIG. 7.



Sections in the Wang-P'ing Coal-Basin. (See Fig. 5. The two upper sections are through Mên-t'ou-kou; the left-hand one below through the Pei P'o, one mile W. of Wang-P'ing Ts'un, and the right-hand one through Pan ch'iao, still further W.)

of a system of E. by W., and a system of NE. by SW. folds. The former is the more marked of the two. The large synclinal fold runs E. and W. through the center of the area, or through Ch'ing-shui Shan, Chiu-lung Shan, and on eastward towards Peking. That part of this fold which lies on the E. side of the mapped area flattens somewhat, and spreads out over a large area, or enters into a synclinal fold of the NE. by SW. system. Thus the coal-bearing group of rocks is brought down below the level of the plains all along the east, southeast, and central parts of the map, Fig. 5. In the central and western part of the field, large E. and W. anticlinal folds extend on either side of the above-mentioned Chiu-lung Shan syncline. The anticlinal fold on the S. side extends W. from the E. side of Ma-an Shan: and the anticlinal fold on the N. side extends W. from near Hao-chia-fang. These anticlinal folds have raised the lower groups of rocks, and subsequent erosion has carried away the overlying coal-bearing groups, so that only the limestones are exposed along these anticlinal areas. A number of small folds and faults break the regularity of these larger folds by running into or across them. Two of these smaller folds which have importance are: the NE. by SW. fold, extending from Wang-p'ing Ts'un to Wang p'ing-k'o, and the NE. by SW. fold, extending along the Mên-t'ou-ko valley. The region, as a whole, is one of severe folding, so that the strata often stand on edge, show a crushed condition, and are broken by numerous small faults.

Coal-Beds.

In the western part of the Wang-p'ing Basin, or around Chai-t'ang, Richthofen found five different series of coal-beds,* distributed through sandstones, shales and conglomerate strata, the whole group of these strata exceeding 7000 ft. in thickness. Only the two lower series were recognized within the mapped area, Fig. 5, though doubtless some of the higher series occur in Ch'ing-shui Shan and in the hills near Wen-shui-yü. Since the third series occurs at a level of 3000 ft. or more above the limestone, its possibility of being in this area is almost if not entirely confined to these two places. Ch'ing-shui Shan con-

* *Letters to the Shanghai Chamber of Commerce*, p. 77.

tains at least 3000 ft. of arenaceous strata, which were not examined for lack of time. The coal-beds examined belong, therefore, to two series, the lower of which (the Liu-li beds of Richthofen) lies from 200 to 300 ft., and the upper (Richthofen's T'ai-ngan beds) 1500 to 2000 ft. above the limestone. The T'ai-ngan beds contain (according to Richthofen, Pumpelly, and the Chinese now working them) 13 coal-seams, varying in thickness from a few inches to 10 ft. Such examinations as I had opportunity to make verify this statement in part. This series is now worked on the NW. side of Hou Shan; on both sides of the W. half of Chiu-lung Shan; on the N. side of Ta-lung Shan, and along the N. side of the ridge lying S. of Pan-ch'iao. From the position of the coal-mines it is evident that at least 3 or 4 separate beds are worked. At the W. end of Chiu-lung Shan we went nearly half a mile into one of the mines, which was temporarily abandoned for New Year's festivities; but our lights went out, and we had to return without seeing the coal in place. The posts left to support the roof in the excavation where coal had been removed were nearly 5 ft. long, so the coal-bed was probably not less than 4 ft. thick.

At the mine about 1.5 mile southwest of Wang-p'ing Ts'un, the tunnel runs back along the coal-bed more than half a mile. The coal, where I could examine it, was but about 1 ft. thick, at best. In some places, highly carbonaceous shales and coal, mixed together, make the bed about 2 ft. thick. A considerable part of it carries only 5 to 6 in. of coal. The general dip is S., at gentle angles; but in some places the seam is horizontal, and in others dips N.

About 1.5 mile southwest of Pan-ch'iao, a recent land-slide has exposed one of these coal-beds, which is, at that place, about 2 ft. thick.

While this series may carry one or two beds reaching in places a thickness of 10 ft., my observations and inquiries lead me to conclude that from 5 to 6 ft., as an average for the best beds, is about all that can be expected.

The Liu-li Beds.—Where Richthofen saw these beds along the Liu-li Ho, 8 or 10 miles south of the mapped area shown in Fig. 5, he estimated that there were not less than 6 seams,

varying in thickness from 2 to 10 ft.* My observations of the Liu-li series in the Wang-p'ing basin were confined to one extremely large bed and two or three small ones. One of the thin seams is worked about 1.5 mile south of Hsi Ts'un, in a mine said to be 30 years old. The present headings are about half a mile from the mouth of the tunnel. The coal-bed, with the included shaly coal, is from 4 to 5 ft. thick. Where I saw it it contained only from 1 to 2 ft. of good coal. The best coal open to inspection is nearly 2 ft. thick at the top of the bed, and nearly 1 ft. at the bottom, with 2 ft. of shale between. At other places the bed carries but from 8 to 10 in. of good coal. It dips about 25° E. and SE.

All the other mines examined belong to the large coal-bed, which is by far the most important in this field. In the mine near Liu-li-ch'ü the coal is badly crushed and faulted, so that it had the appearance of lying in large rooms. It was difficult to estimate the thickness of the bed. It is not uncommon to see quartz-veins and pockets through the coal-bed here. Only a very small quantity of lump-coal is produced at these mines.

At Hao-chia-fang, tunnels in the coal-bed show it to be more than 20 ft. thick. The cross-cuts examined showed usually only one of the enclosing walls; and the broken condition of the strata made it additionally difficult to get the exact thickness. The bed here dips from 15° to 25° E. and SE. This mine furnishes considerable lump-coal of good quality. About half a mile E. of Nan Ts'un a tunnel is driven along the coal-bed for a quarter-mile or more. The part of the bed now mined is about 5 ft. thick, and occupies approximately the same stratum or part of the bed, so that it was impossible to tell the thickness of the whole bed. The dip is from 10° to 25° E. Probably as much as one-third of the coal mined is lump. Some of the coal runs high in sulphur; but otherwise it is of good quality.

The coal-mine about one mile west of Pei-chê-ying shows a seam at least 30 ft. thick. One tunnel has been run in on the coal near the top; and other tunnels, connecting with this, have been driven irregularly through and across the bed. It contains very little waste, but averages high (probably not

* *Letters to the Shanghai Chamber of Commerce*, p. 78.

less than 20 per cent.) in ash. Shale is found at wide intervals through the bed, but it is rarely more than 2 or 3 in. thick. The dip is about 60° SW.

The coal-mine about three-quarters of a mile NW. of Wang-p'ing Ts'un is sunk in the coal-bed from 400 to 500 ft. vertical distance. The bed dips from 80° to 85° SE. The main inclines run zigzag down the coal-bed, next to the foot-wall. From these inclines cross-cuts are run into and across the coal. The two longest open cross-cuts were about 20 and 25 ft. long respectively, but still did not reach the hanging-wall or roof-rock. There were several other cross-cuts which exposed from 10 to 15 ft. of coal. The owner of the mine told me that the coal is over 2 *chang* thick.* Nearly all the coal mined is dust-coal. The little particles have a flaky and "slickensided" appearance. Next to the foot-wall there is from 6 to 12 in. of lump-coal, and occasional lumps are found scattered through the rest of the bed. There is no waste material in the bed, although a considerable part of it will run as high as 30 per cent. in ash.

At the mine about half a mile NE. of Wang-p'ing-k'o, the coal-bed dips from 5° to 10° E. and SE. Only a part of the coal is taken out. The lower part is left, because it contains so much water. The main tunnel exposes from 6 to 7 ft. of the coal near the top of the bed. Over this mined part there is a roofing sandstone stratum about 10 in. thick. The owner of the mine told me that there is from 5 to 6 ft. of good coal above this sandstone. I saw one place where the sandstone had been broken away and the upper coal cut into for about 3 ft., and still the ultimate roof was not exposed. Most of the coal here mined is lump.

Near the village of T'an-fang the coal-bed dips from 75° to 80° N.NW. At two places, from 300 to 400 ft. apart, cross-cuts, almost at right-angles to the strike, expose about 60 ft. of coal. Near the base of the bed there is a sandstone stratum 3 ft. thick, below which there is from 5 to 6 ft. of good coal. One of the two above measurements included this lower stratum, the other did not. In either case the roof-rock was not exposed. According to the Chinese who work in the mine, these measurements give about the total thickness of the bed. At this mine the product is nearly all dust-coal.

† One *chang* is equivalent to 10 Chinese or 11.75 English feet.

From the above examinations it will be seen at once that this bed is uniformly thick, and extends over a wide field. It will probably average 40 ft. or more in thickness; and 25 or 30 ft. is the least average thickness that it could possibly have. Usually the whole bed, with the exceptions of 3 or 4 thin layers of shale, is marketable coal; and nowhere is it probable that more than 4 or 5 ft. of waste material will be found included in the bed. As shown by the following table of analyses, the coals are all hard, dry anthracites.*

Table of Analyses of Chinese Coals.

Analyses Number.	Locality.	Water.	Volatile Hydrocarbons.	Fixed Carbon.	Ash.	Sulphur.	Color of Ash.	Remarks.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		
1....	K'ai-p'ing Coal-Field.	0.64	22.27	71.55	5.54	0.98		Specific gravity, 1.28.
2....	K'ai-p'ing Coal-Field.	0.68	21.03	67.78	10.52	1.16		Specific gravity, 1.32.
3....	K'ai-p'ing Coal-Field.	0.61	19.82	64.62	15.23	0.95		Specific gravity, 1.32.
4....	Tong-shan.	0.62	29.49	65.10	4.78	0.68		This sample was taken from No. 5 seam.
5....	T'an Fang.	2.84	5.42	85.39	6.34	0.14	Cream buff.	Sample of the better quality of coal from this mine.
6....	Near Nan Ts'un.	2.01	2.14	79.91	15.93	0.32	White.	Average sample.
7....	Hao-chia-fang.	1.39	5.26	78.19	15.14	0.22	White.	Average sample.
8....	1¼ miles W.NW. of San-chia-tien.	2.35	3.25	83.41	10.97	0.62	Almost white.	Average sample.
9....	1 mile west of Pei-chê-ying.	1.22	2.49	78.03	18.23	0.26	Cream buff.	Average sample.
10....	1 mile NE. of Wang-p'ing-k'o.	2.67	4.08	82.64	10.59	0.36	Light gray.	Average sample.
11....	1 mile NW. of Wang-p'ing-Ts'un.	1.87	3.33	57.83	36.95	0.11	Cinnamon or dark buff.	Average sample of the fine dust-coal.

NOTE.—Analyses Nos. 1, 2 and 3 are averages of a large number made by experts for the Chinese Engineering and Mining Company.

Analyses Nos. 4 to 11, inclusive, were made by myself from samples obtained at the mines. The ones marked average samples were made from pieces collected with the view of getting a fair average. Naturally they must fail, to some extent, to represent the average of all the coal in the particular mine from which they came; but, taken as a whole, they will closely represent the average coal of the Wang-p'ing basin.

The percentage of ash is high, probably averaging for the whole bed as much as 20 per cent. The percentage of sulphur,

* Around Chai-t'ang, ten or twelve miles west of the mapped area (Fig. 5), bituminous coal is found.

as shown by the analyses, is usually low, but some of the coals run much higher in sulphur than any that were analyzed. The average quality of the coal naturally varies somewhat at different places. Ordinarily the coal is badly crushed; this is especially true where the bed dips at a steep angle. Between Chiu-lung Shan and Wang-p'ing-k'o, where the strata lie more nearly horizontal, it is largely firm lump-coal. The dust-coal, and that containing a high percentage of ash, find a ready market, for the Chinese make the dust into balls and burn it, and, so long as it contains enough coal to burn, it is used. Practically all the outcrops of this bed, except the portion from near Liu-li-ch'ü to Wang-p'ing Ts'un, are dotted with numerous mines.

Another coal-basin lies immediately N. of the mapped area in Fig. 5. On account of its proximity to the plains it will offer good opportunities for mining.

Immediately SW. of the mapped area there is another coal-basin, which promises excellent opportunities for mining, being apparently less highly crushed and folded, and also, like the foregoing, adjacent to the plains. This basin reaches beyond Fang Shan, where Pumpelly says the coal is from 1 to 30 ft. thick.*

During the winter, and to some extent throughout the year, the population of the Wang-p'ing basin region is mainly occupied in mining and transporting coal. Most of the trails, over which the coal must be carried, are exceedingly rough, having been originally paved with stones which, by long use, have been worn smooth and spherical-topped. Only mules and donkeys are suited to carrying the coal over these rough trails. But from the border of the plains to Peking, thousands of camels are used for this purpose.

It is difficult to estimate the amount of coal now mined in the Wang-p'ing basin. Judging from such rough estimates as could hurriedly be made by observing the regularity and number of the mule- and donkey-trains, loaded with coal, which were passing out of the hills, one could not safely place the amount at less than 200,000 tons per year. Most of this coal goes to Peking.

This coal has been mined for several hundred years. Its

* *Geological Researches in China, Mongolia and Japan*, p. 19.

extensive use was noted by Marco Polo, who lived in Peking several years, and made extensive journeys into the interior of China (or Cathay, as it was then called) during the latter part of the thirteenth century. He says:*

"It is a fact that all over the country of Cathay there is a kind of black stones existing in beds in the mountains, which they dig out and burn like firewood. If you supply the fire with them at night, and see that they are well kindled, you will find them still alight in the morning; and they make such capital fuel that no other is used throughout the country. It is true that they have plenty of wood also, but they do not burn it, because these stones burn better and cost less."

It may seem that these coal-fields should have been better known before now, since they have been so extensively mined. Several things have, however, made it difficult to get the desired information. There are a great many coal-beds in the basin, and the Chinese work the thin seams apparently just as persistently as the large ones; so that one who had gone into many of the mines might still have remained ignorant of the best beds. Often the strata are so badly faulted that the thickness of the bed can be only roughly estimated. Again, it is difficult to obtain permission to go into many of the mines.

Fire-clays, roofing-slate, marble and good building-stone are found in this field. The fire-clays are mainly used for making cheap forms of pottery. Most of the roofing-slate occurs about two miles south of Lin-chia Chuang. There are two varieties, one light gray, and the other black. Both lie in beds from 10 to 20 ft. thick, and graduate into sandstone and shales on the sides. The gray slate is said to crack when exposed as a roofing-slate, while the black lasts well and is extensively used for roofing in the villages within from 8 to 10 miles. Near Hua-shih-p'ien, a gray slate, much resembling the one above mentioned, occurs near the top of the limestone group. It is extensively quarried and split into slabs, which may be had in dimensions as large as 5 or 6 ft. across and only half an inch thick; but it is more commonly split into blocks a few inches thick and put to various uses.

The marbles usually crumble to pieces readily under a stroke of the hammer, or when exposed to the weather. Some of them, however, are firm enough to be fairly durable, and some

---

* *Travels of Marco Polo*, by Colonel Henry Yule, vol. i., p. 428.

of them are beautifully white. Great quantities of the limestone rocks are used for making lime. Good building-material, whether limestone or sandstone, is found in abundance.

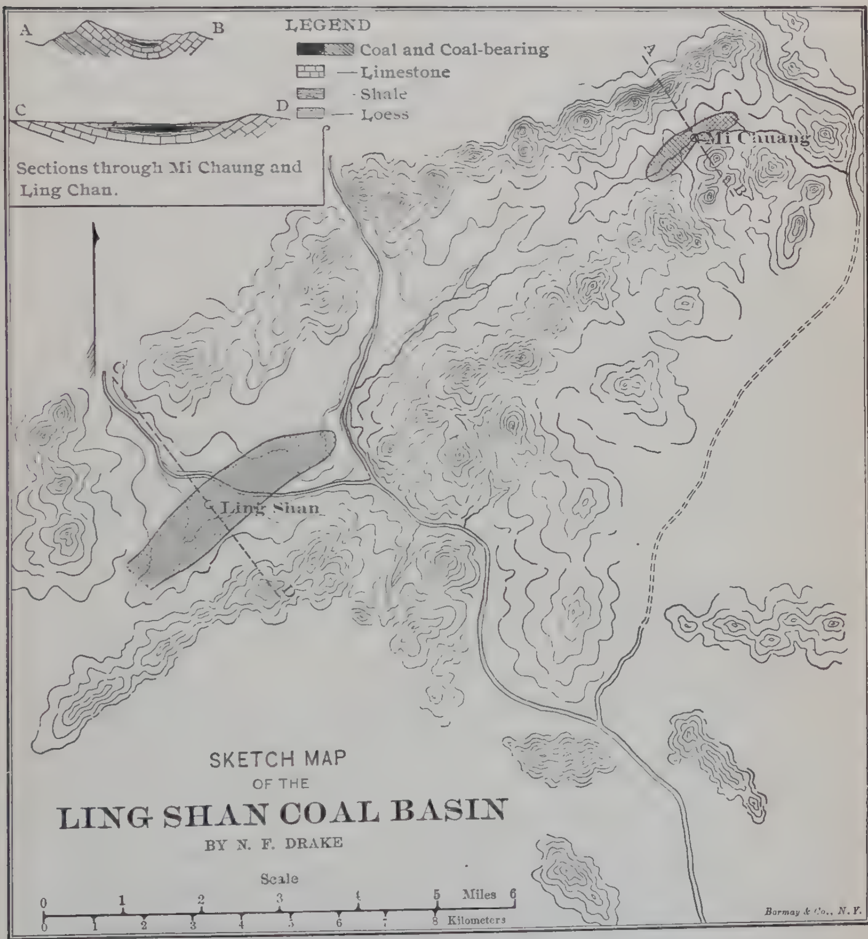
III. The Ling-shan Coal-Basin.

This place is about 50 miles SW. of Pao-ting. The basin lies along one of the synclinal NE.–SW. folds, so characteristic of the western part of the province of Chili. It occupies a little valley, which opens out upon the coastal plains at the SW. corner of the mapped area shown in Fig. 8. A ridge, somewhat broken into isolated hills, bounds either side of the valley. Here, as throughout northwestern China, the coal-bearing strata lie on a floor of limestone, which, being much harder than the overlying rock, stands out in relief, after the softer coal-bearing series have been carried away, until only remnants of them are left in the deeper depressions of the syncline. Usually a covering of loess hides the remnants from view, so that it is difficult to tell the succession of strata. From the dip and position of the limestone on either side of the upper end of the valley, it may readily be seen that usually not more than 200 or 300 ft. of rock could intervene between the limestone and loess. It may therefore be inferred that the position of this coal corresponds to that of the big coal-bed of the K'ai p'ing and Wang-p'ing basins and the Tsê Chou coal-field. I was refused admittance into the various mines which I visited, and saw the coal in place only at one shaft, near Mi-Chuang, where the coal-bed was decayed so that I could not judge of its original thickness. Most of the coal mined about Mi-Chuang was so weathered as to be almost entirely coal-dust. Around Ling-shan, good lump-coal was being hoisted from the mines. At both places the coal is bituminous. The seam has a covering of firm strata, from 100 to 200 ft. thick—and even thicker, in places. The SW. end of this basin passes under the alluvial plains, and probably enlarges to a much broader coal-basin than that of Ling-shan. The coal here lies in a gentle fold at shallow depths, and borders the plains-country, making mining and transportation more simple, and largely insuring an early exploitation. Fire-clays associated with the coal-bearing strata are extensively utilized for making cheap forms of pottery. Fig. 8, illustrating this basin, is simply a rapid sketch-map, in which all the distances are estimated.

IV. The P'ing-Ting Coal-Field.

I have not visited this coal-field, but the work of Richthofen and members of the Peking syndicate, and, to some extent, of other persons, has made it well known. I mention it in order

Fig. 8.



to show the continuity of the coal-beds of Chili and Shansi. Richthofen says of this field:*

"The thickness of the coal varies ordinarily from 12 to 20 ft., and in some places attains 30 ft. . . . . It is impossible to express in figures the extent of the

* *Letters*, etc. (1872), pp. 33–34.

coal-field of P'ing-ting Chou. The present mines constitute a narrow crooked belt, following a line along which the coal-measures crop out, between the horizontal strata of the underlying limestone and the overlying post-Carboniferous. From here the coal-bearing strata extend, between these two formations, to the west, southwest and north, nearly undisturbed for a great distance, in fact through almost the whole of southern Shansi."

V. The Tsê Chou Coal-Field.

That part of this field which has been investigated by me is shown in Fig. 1. My account of it has been given in a former paper.*

VI. General Remarks on the Coal-Fields.

The stratigraphic position of the lower and big coal-beds in all the above coal-fields, from the K'ai-p'ing basin in eastern Chili to the Tsê Chou field in southeastern Shansi, is practically the same, lying as they do, on an average, from 150 to 300 ft. above the Carboniferous limestone. In each of these fields we see only a part of a greater field, so that we are led to believe them to have been originally one continuous bed, or series of closely related beds, of vegetable deposits which have been buried beneath a great thickness of sediments, and subsequently broken and separated by earth-crust movements and denudation, so that they are now more or less independent fields. The apparent average thickness of the principal coal-bed of each of these fields is: for K'ai-p'ing, 18; for Wang-p'ing, 35; for Fang-shan, 20; for P'ing-ting, 20; and for Tsê Chou, 22 ft.

Supposing these fields to represent equal areas, we have a general average of 23 ft. for the whole region. This belt has a linear extent of about 500 miles. If we take a width of only 50 miles and suppose that, because of denuded areas, only one-half is coal-bearing, we still have 12,500 square miles of coal. This would give us about 350,000,000,000 tons, which would be enough to supply the world, at its present rate of consumption, for many centuries. It may be doubted whether the coal-fields above noted represent average conditions along the whole of this extensive belt; but the figures I have given may be accepted with confidence, so far as they go. The coal-fields here discussed are the only ones about which I have reliable

* "The Coal-Fields Around Tsê Chou, Shansi, China," *Trans.*, xxx., 261.

data. In giving estimates, where there is doubt, I have endeavored to underestimate the probable quantities. If we consider all the workable beds, instead of the one big bed, our estimated totals would have to be very much increased. In the K'ai-p'ing coal-field, the big bed contains only about one-third of the workable coal; in the Wang-p'ing basin it contains a much smaller proportion; but in the other fields it covers most of the workable coal. A further study of the coal-fields is likely to show them to be more extensive than we have supposed hitherto.

VII. Geologic Age of the Coal.

From the fossil plants collected by Pumpelly west of Peking, or in the Wang-p'ing basin, Newberry determined the strata from which they came as Mesozoic.* The exact stratigraphic position of these fossils is not given, but most probably they belonged to the upper series of the coal-bearing beds, which would place them anywhere from a few hundred to over 6000 ft. above the lowest series of coal-beds, with which latter series this paper, for the most part, is concerned. In the western part of Chili and the eastern part of Shansi, Richthofen calls the coal-bearing strata the "Productive Carboniferous;" the overlying rocks he calls post-Carboniferous, and the underlying limestone he calls Carboniferous limestone.† The fossil material that I have collected, bearing upon this subject, all belongs in or near the lowest series of coal-beds. Near Tsê Chou, *Fusulina*, sp. (?), occurs in the flint-bearing limestone stratum,‡ which lies about 250 ft. below the big coal-bed. Some coal occurs below the flint-bearing limestone. In the K'ai-p'ing district I have collected different species of *Lepidodendron*. These fossils came from sandstones closely associated, if not interstratified, with the coal-beds. A large piece of shale, containing *Lepidodendron*, sp. (?), from the mines at Tong-shan,

---

* *Geological Researches in China, Mongolia and Japan*, by Raphael Pumpelly, p. 119.

† *Atlas von China*, by Baron von Richthofen. Also *Letters*, etc.

‡ "The Coal-Fields Around Tsê Chou, Shansi, China," by N. F. Drake, *Trans.*, xxx., 261.

was given to me at that place by the secretary of the mining company.

I have made two small collections of fossil plants west of Peking. One came from about 100 ft. below the big coal-bed; the other from carbonaceous shales, which, I believed, immediately underlay the big coal-bed, though they may have come from the shales closely overlying the coal. David White, of the United States National Museum, to whom they were referred for determination, recognizes one fossil as *Asterophyllites equisetiformis* (Schloth, Brongn). Of these fossils he says:

"The *Asterophyllites equisetiformis* is a characteristic upper Carboniferous species. I am disposed to interpret a faint and small finely ribbed fragment as a portion of a large spatulate-leaved *Cordaites*. Another fragment may represent a small Calamarian branch. So far as they go they point strongly to an upper Coal Measures age, though they may run as high as Permian. The small fern-fragment* is somewhat deformed and a little too obscure for determination. It is distinctly Pecopteroid, and probably belongs to the later (Permo-Carboniferous) group of Callipteridia, though it is suggestive of *Cladophlebis*. Its facies is somewhat similar to certain of the lowest Mesozoic forms. Were it not for the recognized mingling, in Australia, South Africa and India, of earlier Mesozoic plant-types with the later Permo-Carboniferous—a circumstance which leads us to anticipate a similar condition in northern China—I should feel disposed to assume that the fern-fragment was of later date than the other fossils."

In Chili and Shansi there appears to be a perfect conformity between the Carboniferous limestones and the overlying coal-bearing series. According to the determination of Newberry and the work of Richthofen, the strata above the lowest series of coal-beds appear to be Mesozoic. From the data now at hand, it seems that at least the lowest series of coal-beds, which are by far the most important, belong to the upper Coal-Measures, or possibly to the lower Permian.

---

* This comes from about 100 ft. below the coal, or apparently lower down than the other fossils.

Biographical Notice of Richard P. Rothwell, C.E., M.E.

BY R. W. RAYMOND, NEW YORK CITY.*

(Mexican Meeting, November, 1901.)

RICHARD PENNEFATHER ROTHWELL was born May 1, 1836, at Oxford, Upper Canada (now the province of Ontario). His father, Rev. John Rothwell, was a native of County Meath, Ireland, where the family (originally, no doubt, a Scottish one) still holds large estates, under a grant from William and Mary. John Rothwell was graduated at Trinity College, Dublin, and became a clergyman of the Established Church. He married Elizabeth Garnett, of Athearn Castle, Ireland, and subsequently came to Canada. It is said that he was a man of liberal views combined with sterling piety, an enthusiastic sportsman and yachtsman, and a pastor who refused for many years to accept any remuneration from his parishioners.

After preliminary education, the subject of this sketch entered Trinity College, Toronto, with the intention of studying law; but a year later he resolved to become a civil engineer, and entered the Rensselaer Polytechnic Institute at Troy, N. Y., where he was graduated, with high standing, as civil engineer, in 1858. He then went to Paris, and entered the Imperial School of Mines, where, by reason of the proficiency he had already acquired in civil engineering, he was able to finish in two years and a half the full three-year course, and to take the degree of Engineer of Mines. In 1861 he took the "practical courses" in mining and ore-dressing at the Mining Academy of Freiberg, Saxony. After traveling in Italy, etc., he went in 1862 to London, where, for the purpose of familiarizing himself with business methods, he entered the offices of W. T. Henley, a manufacturer of wire

---

* In the preparation of this notice, I have been greatly assisted by Mr. Bernard E. Schnatterbeck, for many years Mr. Rothwell's private secretary, who has kindly made researches for me, and furnished, from his own recollection and memoranda, data which I could scarcely have obtained in any other way.

The portrait of Mr. Rothwell, which accompanied this notice in its pamphlet-edition, is the frontispiece of the present volume.

rope and telegraph-cables, whose extensive works were located at North Woolwich. Beginning at the bottom, and discharging clerical duties in the business bureau, he soon attracted attention by his readiness for any kind of service, whether it belonged to his department and came within his regular hours of labor or not. In a word, he showed precisely the character, and followed precisely the method, which modern representatives of organized labor are so vigilant to repress; and as a consequence, he was very soon transferred to the shops and placed in charge of the night-shift—Mr. Henley himself, who then lived in the works, being his own superintendent by day. This was young Rothwell's first professional engagement, and to his inexperience it was rendered more formidable by the knowledge that his predecessor had been frightened away by the threats of the rough foremen and workmen in the wire-drawing and galvanizing-shops. The test was not long in coming. He soon had occasion to discharge workmen whom he had found neglecting their duties; and one morning a foreman, several of whose favorites had been thus discharged for cause, began to threaten the new superintendent after the fashion which had been so successful with the last. Rothwell bandied no words with him, but, in making the usual morning report, mentioned the matter to Mr. Henley, who said at once, "Leave it to me; I will settle it." Knowing that this meant merely a good-natured attempt to smooth things over, possibly with some concession in the way of reinstating the dismissed offenders, and that this would be fatal to discipline, Rothwell insisted that Mr. Henley should come to the shop and let him "settle it." Mr. Henley came; the foreman was called, and in the presence of his superior, Rothwell "laid down the law" to him in plain words, concluding with the admonition, "If you are not careful, you will be discharged, too!" The proprietor, doubtless with secret pleasure in the possession of an assistant capable of such fearless firmness, tacitly supported him; and the offender was dumb with surprise and defeat. There was no further trouble in the works. In later years Mr. Rothwell often said, "It must have been an inspiration; for I really did not know what should be done, and I 'builded better than I knew.'"

Some months later he was sent by the house to the South of

France, to assist in opening and testing certain copper-deposits. On the completion of this work in 1863 he returned to London, and was met at the office-door by Mr. Henley, who asked him how soon he could go to the North of England, to inspect the work in progress upon telegraph-lines from York to London and Birmingham. "By the next train," was the reply; and by the next train he went. This duty involved driving several times over the country between the cities named. At its conclusion he was offered the assistant superintendency of the works with a handsome salary; but although he had become greatly interested in the manufacture of wire rope and telegraph-cables, and in electrical engineering generally, he did not deem it wise to discard for that branch the profession of mining engineering, to which he had devoted so many years of study. Declining Mr. Henley's flattering offer, he returned to Canada and examined the Canadian iron-ore deposits in the interest of the English owners of the Bessemer-steel patents. As Canada presented at that time no important permanent mining work, he came in 1864 to the United States and began practice as an engineer in the anthracite-regions at Eckley, Drifton (which town he laid out) and Wilkes-Barre, where he opened an office and maintained his headquarters until 1873.

During this period of ten years, Mr. Rothwell had charge of the engineering work of a number of large collieries, and for several years was engineer of the Hazard Manufacturing Co. In this capacity, he designed the large rope-making machines which are still in use, after more than twenty-five years' constant service, with occasional and only trivial repairs. These machines were not only entirely novel in design, but also—as, perhaps, they are still—the largest in the world. The machine for laying up the strand has three disks with six bobbins on each—an arrangement which reduces the diameter while increasing the possible speed of the apparatus. It lays up ten tons of wire into a strand. The larger rope-making machine runs at very high speed, and lays up seventy tons of these strands into a rope. Mr. Rothwell invented also, and patented, a device in which rollers take the place of the dies commonly used in laying rope, and a means of laying up a strand while each individual wire is constantly under a strain, automatically

maintained, equal to its working-load. Such an arrangement would greatly increase the working-strength of wire ropes.

During the same period Mr. Rothwell designed and built a number of anthracite coal-breakers, in which he introduced important improvements. Under his advice the Lehigh Coal and Navigation Co. was the first to employ underground locomotives in the anthracite region, namely, at its mines near Mauch Chunk, Pa., in 1869.

In his most valuable work must be included the making of many topographical and railroad-surveys, and the preparation of several important maps. The most famous of these was the contour-map of the highly folded anthracite basin of Panther Creek, made by him in 1869 for the Lehigh Coal and Navigation Co. The remarkable accuracy of this map was shown in the course of important litigation twenty-five years later. According to Mr. W. D. Zehner, the present superintendent, the map is still standard authority, and is frequently consulted with profit in opening new mining work. Another large undertaking of the same kind was the complete survey and the preparation of a property-map, with 10-ft. contours, of about 200 sq. m. of the Wyoming field. This map was subsequently adopted by the Geological Surveys of Pennsylvania and the United States. Still later, he made a survey and a 5-foot contour-map of the southern portion of the Cahaba coal-field in Alabama.

While he resided at Wilkes-Barre, Mr. Rothwell wrote for the *Engineering and Mining Journal* (known, when he first contributed to it, as *The American Journal of Mining*) a number of articles showing his thorough knowledge of the conditions of colliery-ventilation, and the methods of dealing with fire-damp and mine-fires.*

That this knowledge was not mere superficial learning, quoted from others, he proved on more than one occasion. At the

* "Carelessness and Mismanagement in our Anthracite Coal-Mines," etc. *Am. Jour. of M.*, March 2, 1867; "The Relative Economy of Some of the Machines Used in the Ventilation of Mines," *Id.*, May 23, June 6 and 13, 1868; "The 'Useful Effect' of Mine-Ventilators," *Id.*, Jan. 2, 9 and 16, 1869; "Fires in Mines and the Means of Extinguishing Them," *Eng. and Min. Jour.*, July 27 and Oct. 19, 1869; "Extract from the Report of R. P. Rothwell to the Lehigh Coal and Nav. Co," *Id.*, Nov. 30, 1869. Also, "The Preliminary Report of the Committee upon the Waste of Anthracite Coal," *Id.*, Aug. 29, 1871.

Pine Ridge, a very fiery colliery, operated by lessees, a fire was started through the ignition of a "gas-blower" by a powder-blast. This had happened several times before at that colliery, in which such enormous quantities of fire-damp were given off that, whenever for any reason the fan had to be stopped for a period as long as twenty minutes, it was the practice to remove all the workmen and animals. On this occasion the men and mules had been thus taken from the mine before the arrival of Mr. Rothwell, then engineer for the owners of the property. The fire was burning fiercely in a rock-tunnel connected with the return air-way, near the foot of the shaft; and he satisfied himself by personal examination that it could not be walled in or extinguished by any means at command. On the other hand, the fan was of course idle, since the blowing of air into the accumulated fire-damp would create a still larger volume of still more explosive gas. Moreover, in the stagnation of the ventilating-currents caused by the stoppage of the fan, the accumulating fire-damp was becoming mixed with the air already in the mine, and would ultimately be forced to the locality of the fire, with a terrible explosion as the result; and if any natural draft were allowed in the shaft, the flame would attack and destroy the timbering, etc., with still greater pecuniary damage as a consequence. Choosing the least of these evils, Mr. Rothwell urged the closing of the shaft. But the lessees, fearing that they might be held responsible for any damage thus occasioned, would do nothing of that kind without the orders of the owners, who could not reach the place for thirty-six hours. For that period Mr. Rothwell kept the shaft drenched with water, and blew carbonic acid and steam down the upcast, hoping that it might mix with the gas-laden atmosphere of the mine before the latter reached the fire. It is well known that a small proportion of carbonic acid will render fire-damp inexplosive; and in this way the probable explosion might be at least delayed. When the consent of the owners had been at last secured, the work of closing the shaft was begun; but a cage stuck fast at the point where the stopping had to be placed, and it became necessary to remove this cage. This delay was perilous; for the shaft, no longer protected by the temporary expedients above described, was now rapidly filling with fire-damp, and the dreaded explosion might occur

at any moment. Into the shaft Mr. Rothwell led his men, and his men followed him—two significant statements!—and the needed work was done over the depths from which death was swiftly drawing near. To a subsequent inquiry as to his feelings during those critical hours, Mr. Rothwell replied:

"I made my will in good earnest that morning, before going to the mine. Imagine a magazine, filled with a powerful explosive, and the match burning that may at any instant ignite it. You must work, standing in this magazine. If you can complete your task in time, you may prevent the explosion; but it may occur while you are standing there. . . . . Your men do not know the danger, or they would probably not go. They say '*He* knows; and if he goes, it's all right.' You say 'Come, boys!' and they accompany you—as you fear, to death. . . . . No one can understand it who has not had such an experience. There was one young fellow with me who had been injured in a previous explosion in that very shaft. When he heard the words 'Come, boys!' his face blanched; but he never flinched. He did his duty, though he understood the danger. Always thereafter, I held that man in high esteem. There are heroes in peace whose courage exceeds that shown on the battle-field."

Mr. Rothwell succeeded in closing and saving the shaft without accident; but the imminence of the danger was shown by the fact that a safety-lamp, introduced into the shaft a few minutes after it was closed, was filled with flame from the atmosphere. The mine was flooded before the shaft was again opened; and thus was avoided a repetition of the serious loss of life which had attended the last previous Pine Ridge fire under the management of another engineer.

Another colliery-fire in connection with which Mr. Rothwell displayed both skill and courage was the "West Pittston calamity" of May 27, 1871,* in which 24 lives were lost. This mine had but one opening to the surface—a shaft, the breaker at the top of which caught fire and was destroyed, while nearly 50 men were at work below. Mr. Rothwell, who had become in his surveying very familiar with the underground mine-workings, organized parties for the rescue of the entombed miners. At first only dead bodies were encountered; but his knowledge of the locality, and of the principles of mine-ventilation, made him sure that many of the prisoners could be reached and saved—all, in fact, except those who, taken by surprise, had succumbed to the first rush of gas, or those who,

* See *Eng. and Min. Journal* of June 6 and 13, 1871, for my articles upon this disaster.

through their own ignorance, had buried themselves beyond help—for in this case there was no question of fire-damp, or explosive atmosphere, or even flame, in the mine itself. The conflagration of the breaker at the surface had produced great volumes of smoke, carbonic acid, and the yet more poisonous carbonic oxide, which had been sucked into the ventilating-current, down one side of the shaft, to return through the upcast compartment on the other side. As the air-doors below were arranged, this poisonous and suffocating atmosphere would be drawn through the working-places, before thus finding an exit. But by closing some of the doors, the current could be made to take a short cut back to the foot of the shaft, and to leave a large part of the workings filled with pure air. Meanwhile, the pumps having been stopped, water was rising in the bottom; but that was a gradual matter, which need not have frightened any one. For the source of the gases was temporary. After the breaker had been burned up or torn down, they would be no longer manufactured; and the body of gas already in the mine would soon work itself out, and leave the workings accessible somehow.

But the unfortunates below, in their ignorance or panic, had made no attempt to divert the gas-laden current, but, leaving it to spread through the mine, had retreated to a higher working and walled themselves into a comparatively small chamber, posting on the outside of the wall the notice, "We are all here." They were thus placed, by their own terrible mistake, almost beyond the reach of rescue; for they could not live long upon the small supply of air inside the chamber, while the whole mine outside of it was filling fast with the gases through which any relief-party must find its way. Against such difficulties a party of volunteers, led by Mr. Rothwell, made its way to the barrier, broke through, and found "all there" indeed, but all unconscious, and many already dead. In successive trips they brought out through the stifling atmosphere, and at last through the rising water, first the living and then the dead. Half of the entombed victims were ultimately restored to life; to the other half help came too late. The rescuers escaped death, though some of them, including Mr. Rothwell, were overcome, and revived with difficulty. In the successful execution of this daring exploit, the consummate skill and

executive vigor as well as the heroic courage of Mr. Rothwell were essential factors.

These are stories which a man's friend ought to tell with pride and gratitude over his grave—especially when the man himself never published them, or claimed credit for the deeds they involved. I remember that, as editor of the *Engineering and Mining Journal*, I received, in June, 1871, a communication from Mr. Rothwell, in which he explained the mistake of the workmen and the consequent loss of many lives, without dwelling at all upon the incidents of the rescue. And I remember a lecture on anthracite-mining, given by Mr. Rothwell in 1878 in the course at the Cooper Union, of which I was then director. In one part of it he described vividly the conditions existing underground after a colliery-explosion or fire, when the workings were full of "after-damp," "choke-damp," "smoke," etc. But he suppressed so completely any note of personal experience that I could not resist the impulse to rise at the close of the lecture and tell the great audience how the lecturer had come to know so much about his subject! He had received close attention and hearty applause during his brilliant address; but my little story at the end brought down the house. It did not need to be eloquent. The simple facts were enough.

It was during Mr. Rothwell's residence at Wilkes-Barre that he united with Eckley B. Coxe and Martin Coryell in issuing the circular of April, 1871, in response to which twenty-two mining engineers met at Wilkes-Barre on May 16, and organized the American Institute of Mining Engineers. Mr. Rothwell was elected the chairman of that meeting, but in the permanent organization he claimed no official honors. Of his two associates in founding the Institute, Mr. Coxe became at once a vice-president, and Mr. Coryell the secretary; but he accepted the position of simple manager. In 1872, 1873 and 1877 he was a vice-president; but it was not until 1882 that, without any suggestion on his part, he was unanimously elected president of the Institute. In 1898, 1899 and 1900 he served again as manager.

The following is a list of his contributions to the *Transactions*, arranged in chronological order. The titles of papers are in italics:

Contributions of Mr. Rothwell to the Transactions.

* This paper, read before the Institute at the Bethlehem meeting, Aug., 1871, was printed Aug. 29, 1871, in the *Eng. and Min. Journal,* then the organ of the Institute, which issued no volume of Transactions in 1871. See *Trans.*, xiv., 609, footnote.

To this list may be added, as cognate in character, the article on "American Mines," written by Mr. Rothwell for the work entitled *One Hundred Years of American Commerce*, edited by Chauncey M. Depew, and published by D. O. Haynes & Co., N. Y. City, in 1895. It would be impracticable to enumerate here his innumerable contributions, signed or unsigned, to the *Engineering and Mining Journal*, after he became one of its editors. The columns of that publication must be searched to find them.

Partly through his contributions to the columns of the *American Journal of Mining* (later, and now, called the *Engineering and Mining Journal*), of which I was editor, and yet more by reason of our co-operation in the organization of the Institute, Mr. Rothwell and I became acquainted. In January, 1874, he became an editor, and afterwards the owner of the journal. I had at that period acquired the somewhat doubtful asset of this ownership, which entailed upon me a considerable annual loss—partly because the enterprise was not yet established as a business, partly because I could not spare from other professional work the time and strength required for effective business management, and found it easier to pay the debts of the concern than to make it pay its own expenses. From the time when Mr. Rothwell assumed control of it, he gave himself to it with intense and unwearied devotion. What it became in his hands I will not here undertake to describe. It is its own best witness; and its subscribers are its best judges. But I cannot forbear to say, out of a very wide familiarity with technical journals of its class, that I do not think it now has, or has ever had in the past, among such periodicals, an equal in the world for combined commercial and technical value. I may say this the more freely since I have not been, for many years past, in any way concerned in its editorial management. Even while, under the friendly urgency of Mr. Rothwell, I continued to bear the title of his editorial associate, I was subject to his superior decision; and although I became, not seldom, restive under his polite but firm control of its columns, I recognized that he was the responsible manager, and (after more or less protesting) usually yielded to his decisions. Finally, when the *Journal* took editorially a position on the "silver-question" with which I could not agree, and for

which I found I was being held responsible in many quarters, I withdrew my name as editor, and became nominally a "special contributor," without the least change in my cordial personal relations with Mr. Rothwell.

I mention this comparatively insignificant matter here, because it presents a striking illustration of Mr. Rothwell's manly independence as a journalist. I was a "gold-bug;" an uncompromising advocate of the single gold standard; one of the experts to whom the United States coinage act of 1873 had been submitted before its presentation to Congress; and hence one of those who intelligently, with their eyes open, had approved and furthered the "crime of 1873," if crime it was. I would not have been surprised if Mr. Rothwell had taken the opposite view, or if, influenced by the wide circulation of the *Journal* in the West, he had at least abstained from editorial advocacy of either side, in the hot political fight which was waged on an economical subject. It was really not necessary that he should take sides at all in the matter. But what he did was to propose a solution not acceptable to either party; to advocate it persistently, not only in the *Journal*, but in a separate book* on the subject, and to do this at the cost of a great loss of patronage, both East and West. I did not think his peculiar view was sound, and I could not afford to be understood as agreeing with it; but I thought then, and I think now, that it furnished an instance of courage and independence, unaffected by personal interest, quite unusual in my experience. I say "personal" interest, for by that time all that Mr. Rothwell had in the world, either in property or in ambition, was staked on the success of the *Journal*. I am glad to know that, after a period of serious loss of patronage, his enterprise recovered its prestige, and was even, as I trust, all the better supported for the exhibition of conscientious independence which he had made.

Not content with the arduous labors of the editorial and business management of the *Journal*, Mr. Rothwell (as head of the Scientific Publishing Company, of which he was the principal stockholder) published many scientific and professional books of timely value, and, above all, began in 1893 the annual

---

* "A Plan for Universal Bimetallism under the Control of an International Monetary Clearing-House." See also *Eng. and Min. Jour.*, Dec., 1892.

publication of a statistical and technical work, *The Mineral Industry; its Statistics, Technology and Trade*, covering the whole field of the world's production and the world's mining and metallurgical progress. The first volume contained historic summaries of past years; and eight succeeding volumes have both continued and perfected the record. It would be easy to point out in such a summary, especially in one published (as this one has been) with such exceptional promptness, after the termination of each calendar year, errors of detail from which more leisurely official documents may be free; but the fact remains beyond question that Rothwell's "Mineral Industry" has possessed not only timely, but permanent value, and that the conception of such a plan, and its execution with so high a degree of intelligence and thoroughness, is well nigh unparalleled in statistical and technical literature. International recognition of this achievement came to him in 1898 in the gold medal of the *Société d'Encouragement pour l'Industrie National de France.*

Concerning his editorial work, I quote the testimony of his associate, Mr. F. Hobart:

"Besides the knowledge acquired by study and experience, Mr. Rothwell possessed in an eminent degree the qualifications of an editor. He had a quick perception of the value of 'matter'; he had an extraordinary memory and a keen sense of fitness and proportion. In an intimate association of over eight years in the editorial work of both the *Journal* and the *Industry*, the writer learned to appreciate and rely upon these qualities, and was never disappointed in the result. Beyond—and perhaps as a consequence of—these qualities, he was never one of those who considered his work complete. He was a constant student and always open to new impressions, and he never hesitated to correct his work when convinced that it required amendment.

"The statistical side of his work always appeared to him of especial importance, and he gave much time and thought to it. He was well known among statisticians, both in this country and in Europe. Few men could analyze a compilation of figures more quickly and more thoroughly; and few could state results in figures in so compact and clear a form. It is to this that much of the success which *The Mineral Industry* has attained is due. He quickly detected errors and discrepancies of this kind.

"Early in his work Mr. Rothwell set a high standard for the *Engineering and Mining Journal*, and to this he constantly strove to adhere—or rather to approximate, for his disposition was never to be fully satisfied with results, but to aim at something better. His independence of thought and action has been referred to by Dr. Raymond; and indeed it was always his habit, in considering the treatment of a question, to think only of what was right, and not of possible consequences to himself. While favoring legitimate mining enterprise in every way, he had no mercy for fraudulent enterprises and their promoters, as the columns

of the *Journal* show, and as its old readers will reçall. This was a direct result of his determination always to seek the best.

"He always laid great stress on the *Journal* as an educational force; and it was probably this thought which led him to take an interest in correspondence-schools, and finally to connect himself with the United Correspondence-Schools of New York, of which he had been president for two years previous to his death."*

Concerning the professional work of construction, design, opinion, advice and invention performed by Mr. Rothwell during his long and active practice, I am unable to present a complete record. The incidental references in my own foregoing remarks, or in his professional papers, to his wire-rope machine, cylindrical roaster, pressure-filter, method of mining bodies of soft-ore, etc., hint at some of his inventions or improvements in practice. In connection with Hall's new method of laying submarine tunnels and tubes, which Mr. Rothwell described in a paper before the Institute,† he devised and patented‡ an elaborate improved system, applicable also to shafts in soft ground or quicksand. This patent I have had occasion to examine with care; and the method embodied in it seems to me to be sound, thorough and efficient. It was adopted for trial in sinking a shaft in Calcasieu, Louisiana, through a great depth of quicksand, to the famous sulphur-beds of that locality. But the experiment began with the attempt to restore and utilize an old shaft on the property, and this shaft was unexpectedly swamped by quicksand before the new system had been installed in it. A method of extracting the sulphur by means of hot water, through drill-holes, was subsequently adopted, and consequently no test was made of Mr. Rothwell's plan. So far as I know, it has never been tried in practice since. The thwarted experiment in Louisiana may have been, for the system itself, a blessing in disguise; for the Calcasieu problem far exceeded in difficulty and risk (that is to say, in area, depth, and pressure of quicksand, to say nothing of sundry disturbing influences of exceptional character underground) anything heretofore encountered by mining engineers; and, though I gave a favorable professional opinion concerning Rothwell's

---

* *Eng. and M. Journal*, April 20, 1901.

† *Trans.*, xiv., 770.

‡ U. S. patents, Nos. 428,021, dated May 13, 1890, and 549,586, dated Nov. 12, 1895.

scheme, I fully recognized that its failure under these exceptional conditions would not be decisive against its value for such undertakings as have been hitherto considered at all practicable —though, of course, its success at Calcasieu would have been an astonishing achievement. In fact, after examining all other methods recognized by engineers, but before studying this one, I had given a formal opinion that not one of them, except, possibly, the Poetsch process, could be expected to deal with the case. The practical value of Rothwell's design remains to be determined; and, for practical purposes, it had better be determined first under conditions not unique.

Besides his membership in the American Institute of Mining Engineers, above referred to, Mr. Rothwell was a member of the *Société de l'Industrie Minérale*, and of the Geological Society of France (Paris), and an honorary member of the Institution of Mining and Metallurgy, London, England, and of the Australasian Institute of Mining Engineers, New South Wales. He was a Fellow of the Geological Society of London, England; of the Imperial Institute, London, England, and of the Royal Statistical Society of Great Britain, and a member of the Federated Institute of Mining Engineers, Great Britain; of the Society of Chemical Industry, London, England; of the American Society of Civil Engineers; of the American Statistical Association; of the American Trade Press Association, and of the New England Free Trade League. He was a member of the Lotos, the Reform, the Hardware, the Larchmont Yacht and the New York Press Clubs. He had charge of the statistics of gold and silver for the United States Census in 1890. Some of the organizations named in the above list have already adopted appropriate tributes to his memory, and others will undoubtedly do so. Rather than wait for a complete record (which might, moreover, be too voluminous for insertion here), I omit even those resolutions of which I have received copies.

Mr. Rothwell died April 17, 1901, after a considerable period of relatively impaired health, followed by a brief acute illness, the fatal termination of which was not anticipated until it was close at hand. The cause of death was cancer of the stomach. In spite of pain and increasing weakness, he kept his hand upon the helm of business until a day or two before the end.

The foregoing sketch represents but imperfectly the character and achievements of Richard P. Rothwell. Yet when I say of him that he was one (and in many respects the most influential*) of the three founders of the American Institute of Mining Engineers; that he practically created, or, at least, developed to its full strength and scope, the *Engineering and Mining Journal*, as the recognized organ of the technical practice and the business interests of mining and metallurgy; and that he conceived and successfully maintained the colossal undertaking of that annual cyclopœdia, the *Mineral Industry*, I say enough to vindicate for him a foremost place among the leaders of professional progress.

In conclusion, I would simply add my personal testimony of the unbroken friendship which existed for more than a quarter of a century between Mr. Rothwell and myself, and during which, notwithstanding many disagreements, there was not one quarrel, and not one doubt, on my part, of his sincerity, integrity and loyal affection.

The Alloys of Lead and Tellurium.

BY HENRY FAY AND C. B. GILLSON, MASS. INST. OF TECHNOLOGY, BOSTON, MASS.

(Mexican Meeting, November, 1901.)

For several years past, investigations on the chemistry of tellurium have been carried on in the laboratory of this institution. The methods of preparation of pure tellurium† and the estimation of tellurium‡ have been studied, and an attempt to determine the atomic weight of tellurium is now in progress. All these problems had been investigated, however, along purely theoretical lines; and it was thought desirable to study the more practical application of the metal, which can now be had in considerable quantities as a waste product in the refining of copper-ores. In its physical and chemical properties tellurium is very similar to antimony, and it was thought

* I have reason to believe that the plan originated with him.
† Norris, Fay and Edgerly, *Am. Ch. J.*, vol. xxiii., p. 105.
‡ Norris and Fay, *Am. Ch. J.*, vol. xx., p. 278.

probable that it might replace antimony in certain alloys. Hence, it was decided to prepare and study the alloys of lead and tellurium.

Recently developed physico-chemical methods have thrown much light on the nature of solutions; and it has been shown that the properties of alloys are entirely analogous to those of solutions. The methods which have been of greatest service in studying the nature of alloys have been the determination of the fusibility curves, and the study of the structure by means of the microscope. These two methods give results which entirely corroborate each other. By the older methods of investigation, such as studies of the heat of formation, heat of solution, electrical conductivity, etc., the different methods not only did not give definite conclusions with regard to the constitution of the alloys, but, in most cases, led to different conclusions. The problem was undoubtedly much more complex than the study of ordinary chemical compounds, since in the latter case it was possible to use solvents which would not affect the nature of the substance when dissolved, whereas, for alloys, there was no solvent which would not entirely change the character of the substances. The work of Le Chatelier, Gautier, and Heycock and Neville has led, however, to definite conclusions; and the fusibility-curves established by them have been found to be entirely analogous in character to the curves found for mixtures of simple chemical substances.

With the aid of the microscope the results obtained in the determination of the fusibility-curve have been confirmed. The microscope gives an approximate analysis of the different constituents contained in the alloy, and, in many cases, a clue to the order of solidification of the several constituents.

Various alloys composed of two metals have been found to give curves of fusibility, which fall under one of the three following classes, illustrated in the diagrams, Figs. 1, 2 and 3.

1. Two metals which form solid solutions give a straight-line curve connecting the two freezing-points. (See Fig. 1.)

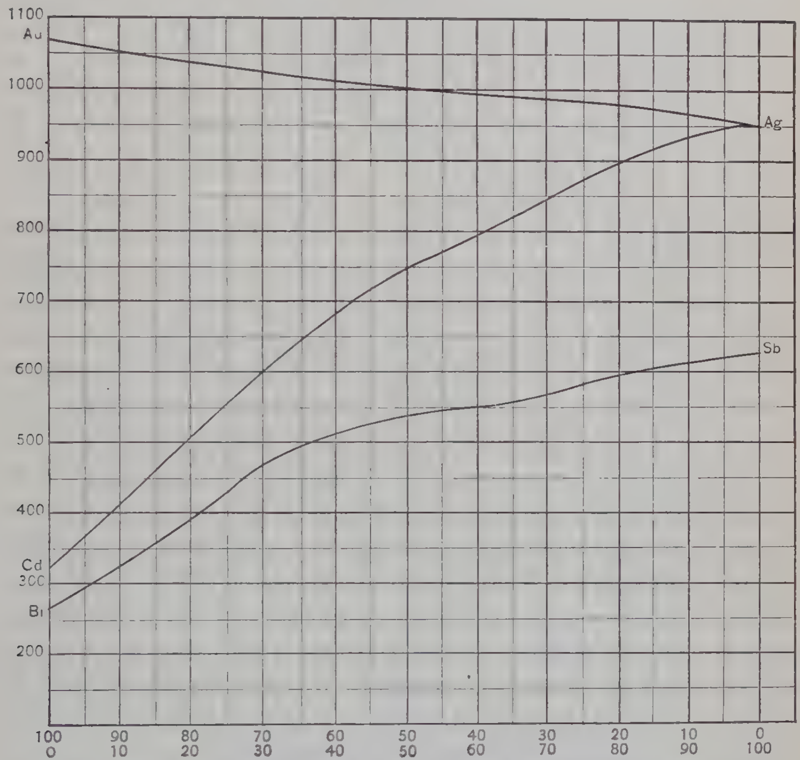
2. Two metals which form neither solid solutions nor compounds give a curve of two branches meeting in a eutectic,* the

* The eutectic is that alloy, of definite composition and constant melting-point, in which the constituents are in equilibrium at all temperatures. Its melting-point is lower than the melting-points of its constituents, and its composition is not altered during solidification.

freezing-point of which is lower than the freezing-point of either metal. (See Fig. 2.)

3. Two metals which form one or more compounds give a curve, the number of branches of which is $2n + 1$ where n represents the number of compounds. In this class one of the compounds may form a solid solution with one of the pure

FIG. 1.



Diagram, Showing Melting-Points of Gold-Silver, Cadmium-Silver, and Bismuth-Antimony Alloys. (The ordinates represent degrees C. ; the abscissæ, percentages of the two constituents of each alloy.)

metals, which would, consequently, modify the character of the curve, and therefore change the number of branches. (See Fig. 3.)

The examples of these classes of alloys, together with their fusibility-curves, shown in Figs. 1, 2 and 3, are offered, not as a complete summary of the work actually accomplished in this field, but merely to illustrate the nature of the work. Many

of these curves have been plotted from Gautier's work,* and have not been experimentally confirmed.

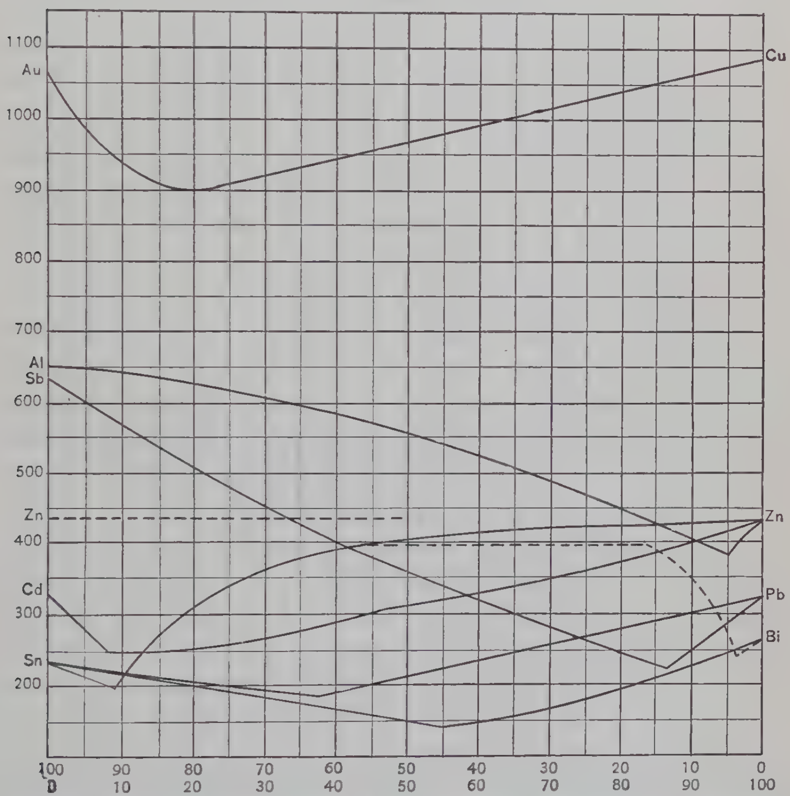
In Fig. 2 the minimum points correspond to the eutectic mixtures; in Fig. 3 the maximum points in the curves correspond to definite compounds, and the minimum points to the eutectic alloys.

The study of the microstructure of these three classes of alloys confirms very decisively the fusibility-curves. In the first class it is known that the solvent and dissolved substance separate out together. The microstructure of metals which form solid solutions shows a homogeneous mass, in which it is difficult, if not impossible, to distinguish between the two constituents. The alloys of gold and silver, cadmium and silver, and antimony and bismuth would show on microscopic examination to be composed of homogeneous mixed crystals of the two constituents. In the second class, where the freezing-point of the pure metal is considerably lowered by the addition of the other metal, we know that there is first a separation of pure solvent, and that, as the temperature of the solution is lowered, the pure metal continues to separate until the concentration of the resulting solution has reached that of the eutectic alloy, when the mass solidifies as a whole. The microscopic constituents, consequently, should be the pure metal and the eutectic—the amount of each depending upon the proportion of the two metallic constituents. As the eutectic is the alloy in which the two constituents are mutually saturated, and as the two separate simultaneously, we should expect to find a structure made up of alternate layers of the two metals. This is actually found to be the case, and the structure for all eutectics is very characteristic, resembling the fine-lined markings of the human thumb. The eutectic may consist of two metals, of metal and a compound, or of two compounds; but in all cases its structure is very characteristic and easily recognized. This class of alloys may be illustrated by taking as an example the fusibility-curve of the tin-bismuth alloys, Fig. 2. The branch of the curve between 45 and 100 per cent. of tin represents the separation of tin and the eutectic of tin and bismuth, the amount of each depending upon the composition. As, by increasing the per-

* Gautier, *Bull. Soc. d'Encouragement*, 1896, vol. i., p. 1293.

centage of bismuth, we approach the composition of the eutectic alloy, 45 per cent. tin, more and more of the eutectic structure will appear until the whole mass consists of the eutectic alone. The additions of bismuth to tin have successively lowered its freezing-temperature until, at 55 per cent. of bismuth, the low-

Fig. 2.



Diagram, Showing Melting-Points of Gold-Copper, Aluminum-Zinc, Antimony-Lead, Zinc-Bismuth, Cadmium-Zinc, Tin-Zinc, Tin-Lead, and Tin-Bismuth Alloys. (The ordinates represent degrees C.; the abscissæ, percentages of the two constituents of each alloy.)

est freezing-temperature has been reached, and both metals separate simultaneously from solution. With the further addition of bismuth, the freezing-temperature begins to rise, and the branch of the curve between 55 and 100 per cent. of bismuth represents the separation of bismuth (which is now the solvent) and the eutectic alloy, the relative quantities of each

being dependent upon the percentage-composition. As the composition approaches that of the pure metal, there will evidently be an excess of the pure metal over the eutectic. The presence of compounds of the third class is usually recognized by their crystalline form, the forms of some of them being very characteristic, such as is the case for the compound $SnCu_3$. When, however, a compound forms a solid solution, the detection of the two constituents is much more difficult. To illustrate the third class of alloys, we may take as an example the alloys of nickel and tin, giving a three-branch curve of fusibility, which is nothing more than a combination of classes 1 and 2. The first class is represented in the branch of the curve between the maximum point at 67 per cent., corresponding to the compound NiSn, and 100 per cent. of tin. The microscopic constituents between these two points consist of homogeneous mixed crystals of the compound NiSn and pure tin. The compound forms a eutectic alloy with nickel. Whether we consider the compound NiSn or pure nickel as the solvent, the freezing-point of each is lowered by addition to the other until they are mutually saturated. We then have the eutectic alloy, melting at the lowest possible temperature at which it is possible for a mixture of these two constituents to melt.

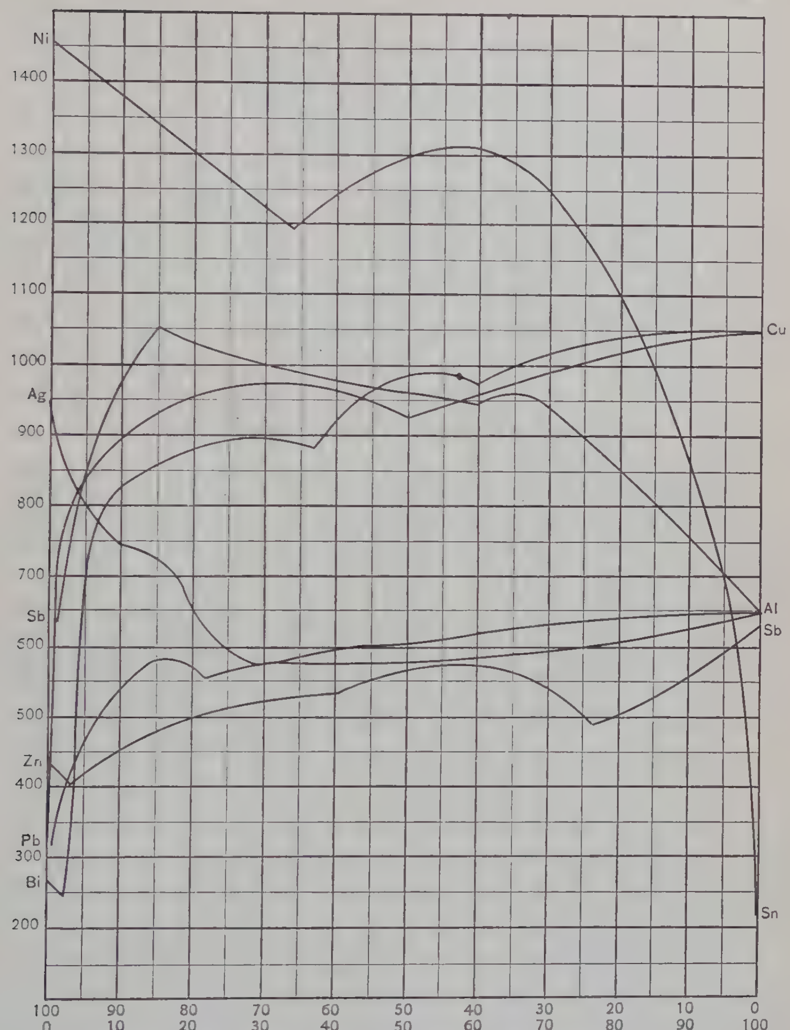
The microscopic constituents of the branch between 67 and 100 per cent. of nickel consist of pure nickel and the eutectic of nickel and the compound, NiSn; between 67 and 33 per cent. of the compound and the eutectic.

The Preparation of Pure Tellurium.

The metallic tellurium required was extracted from the slime which is the waste product of the electrolytic process employed at the Baltimore copper-works in the treatment of copper-mattes from the West. This residue, after the removal of silver and copper, consists principally of the sodium salts of silicic, selenous, and tellurous acids, the last named being in large excess. The process by which the necessary liquid solution is secured and the copper is refined, has been described by Whitehead;* and the separation and preparation of pure tellurium has also been recently described.† It will

* *Jour. Am. Chem. Soc.*, 17, 280, 849. † *Am. Ch. J.*, vol. xxiii., p. 105.

FIG. 3.



Diagram, Showing the Melting-Points of Nickel-Tin, Silver-Aluminum, Antimony-Copper, Zinc-Antimony, Lead-Copper, Lead-Aluminum, and Bismuth-Copper Alloys. (The ordinates represent degrees C.; the abscissæ, percentages of the two constituents of each alloy.)

suffice to say here that the method consists in the precipitation of the metal and its conversion into basic tellurium nitrate, $Te_2O_3.(OH).NO_3$. This finely crystallized salt serves as an excellent means of obtaining pure tellurium. The basic nitrate is decomposed by heat; the oxide thus obtained is dissolved in

hydrochloric acid; and from this solution the metal is re-precipitated by means of sulphur dioxide. Crystallization of the basic nitrate from a nitric acid solution removes selenium completely from the tellurium, and also furnishes a very convenient method for the separation of other metals.

Tellurium thus prepared is a black amorphous powder. After fusion and cooling, however, it is decidedly crystalline, resembling antimony very markedly in this respect, but in luster nearly as bright and white as silver. It is capable of taking a high polish, but, on account of its brittleness, it is difficult to get an entirely smooth surface. Its freezing-point is 446° C., and its specific gravity 6.243.

The Preparation of the Alloys.

Having obtained in this way about 250 grammes of pure tellurium, we made seventeen alloys, varying in composition from 98 per cent. lead and 2 per cent. tellurium to 5 of lead and 95 of tellurium.

The lead used in the experiments was from two different sources, but both samples were as pure as could be obtained. The freezing-point of both samples was found to be 322° C.

In mixing the alloys, granulated tellurium was added to molten lead contained in a porcelain crucible. In every case, it was found necessary to add from 2 to 5 per cent. more than the amount theoretically required, in order to secure the composition desired. After the metals had been brought together, the molten mass was thoroughly stirred, and the heat continued for a few minutes, in order to insure complete fusion. The mass was allowed to cool in the smoky flame of the burner. In all cases when the two metals were brought together in the crucible there was an evolution of light and heat, and the mass solidified to a hard cake, which in some cases was melted only with the aid of the blast-lamp. This hard mass, as will be shown later, was lead telluride.

Throughout the operation, the fused metals were protected from oxidation by a layer of finely-powdered charcoal spread over the surface.

The Analysis of the Alloys.

To obtain samples for analysis, a vertical section one-eighth in. thick was sawed out from the mass of each alloy, one-half

being used for analysis and the other half for microscopical examination. As the alloys varied considerably in hardness, it was possible to pulverize some of them, while from others the sample was obtained by filing.

No reliable procedure was known for the determination of either lead or tellurium in the presence of the other, and many methods were tried without much success. It was thought that tellurium might be separated by taking advantage of the insolubility of its basic nitrate in strong nitric acid; but concordant results were not obtained. It was also found impossible to remove the lead as sulphate, and to precipitate the tellurium from the sulphuric acid filtrate.

The method finally employed for the analysis of all of the alloys consisted in volatilizing the tellurium as chloride, in a current of chlorine gas, and weighing the residue of lead chloride. It was found that by keeping the temperature near the fusing-point of lead chloride, all of the tellurium chloride could be distilled off, without loss of lead. This method was found to be very convenient, accurate, and rapid. Table I., showing the tabulated results of the analyses, gives the percentage of lead as found by analysis, and that of tellurium as calculated by difference.

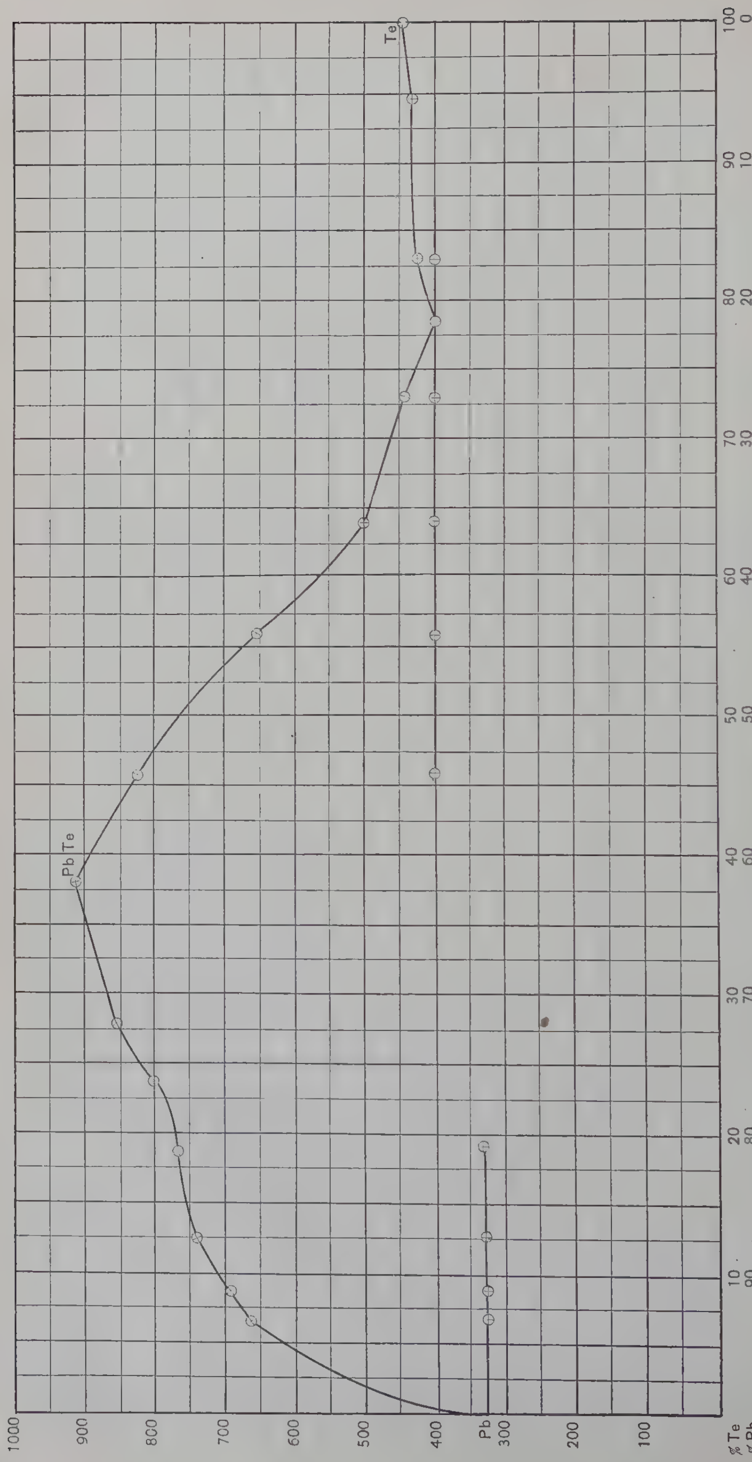
The Determination of the Freezing-Points.

All determinations of freezing-points were made with a Le Chatelier thermo-electric pyrometer. The electric couple of this pyrometer consisted of a pure platinum wire and a wire of platinum alloyed with 10 per cent. of rhodium. These wires were soldered to copper-wire leads, connecting them with a galvanometer of the d'Arsonval type, which reflected a beam of light upon a millimeter-scale. The junction was calibrated by noting the deflections corresponding to the following known points, stated in centigrade degrees:

	Boiling-Points.		Freezing-Points.
Water,	100	Aluminum,	660
Naphthalene,	218	Gold,	1072
Sulphur,	445	Copper,	1095

The deflections were such that by reading to tenths of a millimeter one could estimate the temperature within 2° C.

FIG. 4.

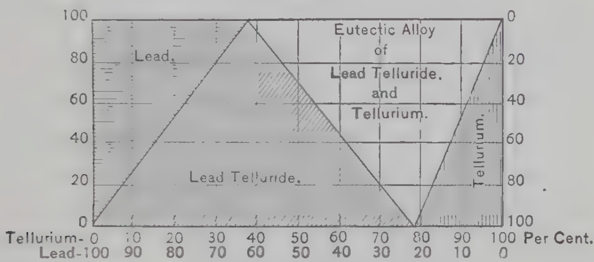


Diagram, Showing Lower and Higher Freezing-Points of Lead-Tellurium Alloys.

(The ordinates represent degrees C.; the abscissæ, percentages of lead and tellurium respectively.)

Since both lead and tellurium alloyed very readily with either platinum or platinum-rhodium, it was found necessary to protect the junction. This was satisfactorily effected by threading the wire through a piece of hard glass tubing of small diameter, bent into a long, narrow U.

FIG. 5.



Diagram, Showing the Percentage of Each Constituent in Various Lead-Tellurium Alloys.

In determining the freezing-point of an alloy, the junction was placed in the molten mass, contained in a porcelain crucible, and readings were made every ten seconds during the cooling. In this way the freezing-points given in Table I., and shown graphically in Fig. 4, were determined.

TABLE I.—*Freezing-Points and Percentage-Composition of Lead-Tellurium Alloys.*

(Shown Graphically in Fig. 4.

Alloy. No.	Lead. Per cent.	Tellurium. Per cent.	Lower Freezing-Point. Deg. C.	Higher Freezing-Point. Deg. C.
1	109.00	......	......	322.
2	94.00	6.00	320.	665.
3	91.30	8.70	325.	695.
4	87.50	12.50	322.	743.
5	81.40	18.60	322.	775.
6	76.40	23.60	......	805.
7	72.20	27.80	......	859.
8	61.97	38.03	917.	917.
9	54.10	45.90	397.	828.
10	43.70	56.30	400.	656.
11	35.90	64.10	400.	550.
12	27.20	72.80	400.	445.
13	21.50	78.50	400.	400.
14	17.00	83.00	400.	427.
15	5.60	94.40	......	433.
16	......	100.00	446.	446.

The Microscopical Examination of the Alloys.

Each sample for microscopical examination was one-half of the vertical cross-section, one-eighth inch thick, which had been sawed from the center of the mass of each alloy; the other half of the section having been used for analysis. The surface was first smoothed with a file, and then by rubbing under water on an Arkansas stone. The final polish was accomplished by rubbing very lightly on rouge placed on chamois. The surfaces were all etched with very dilute hot nitric acid, which brought out the structure satisfactorily. The alloys containing not more than 38 per cent. of tellurium could be etched by polishing in relief; but the process was laborious, and had no particular advantage over etching with nitric acid.

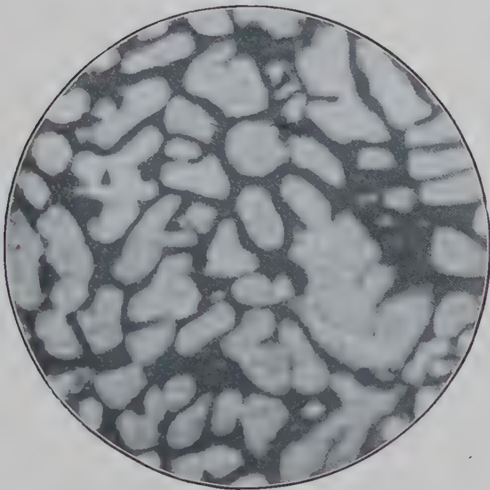
All the photographs from which Figs. 6 to 12 have been made were taken at 95 diameters' magnification, and have been reproduced by the engraver at 80 diameters.

Discussion of Results.

Upon inspection of the freezing-points given in Table I., and shown graphically in Fig. 4, it is seen that the freezing-point of pure lead is raised to a remarkable extent by the addition of small amounts of tellurium. For example, in alloy No. 2 the addition of 6 per cent. of tellurium has caused a rise in the freezing-point of over 300° C.; but the further addition of tellurium has not caused a proportionate elevation of the freezing-point. The maximum freezing-point, 917° C., was reached when the composition of the alloy corresponded to that of lead telluride, PbTe. The formation of lead telluride explains the evolution of light and heat, and the rapid rise in the freezing-point caused by bringing together the two metals. The metallic lead very easily becomes supersaturated with the lead telluride, and the latter separates out of the solution. As the cooling is carried further, the excess of lead separates. This separation of the two constituents is well shown in the freezing-points of alloys Nos. 3, 4 and 5. The lead point, however, disappears, or becomes so weak as not to be noticeable, when the tellurium is in excess of 20 per cent. With an increase of tellurium beyond 38 per cent. the freezing-points are lowered; and the fall continues until a temperature of 400° C. is reached.

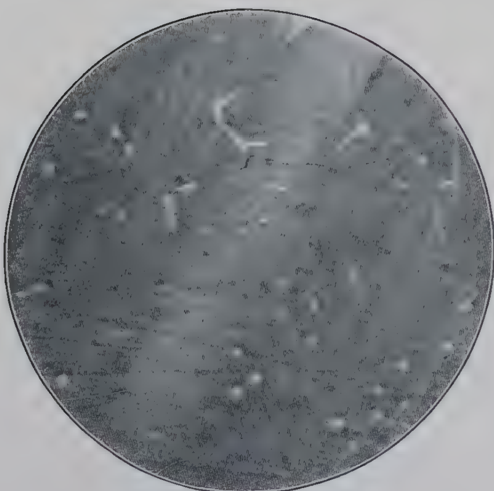
At this point the alloy solidifies as a whole, and contains 78.50

FIG. 6.



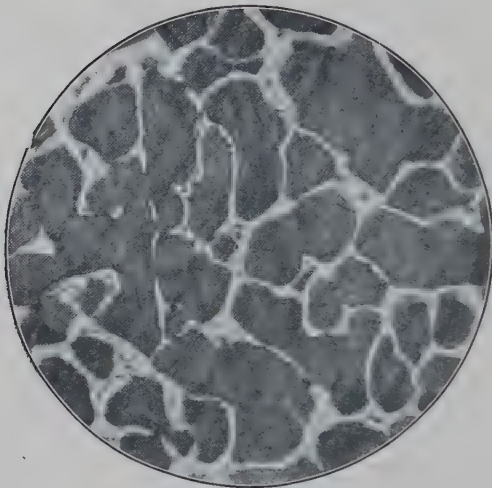
Alloy No. 4. Lead and Lead Telluride.
(80 Diameters.)

FIG. 7.



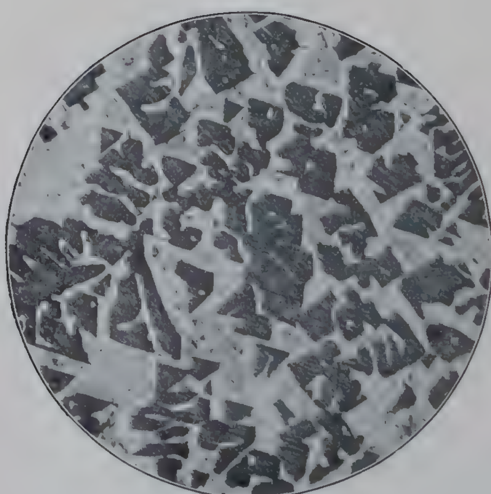
Alloy No. 8. Lead Telluride.
(80 Diameters.)

Fig. 8.



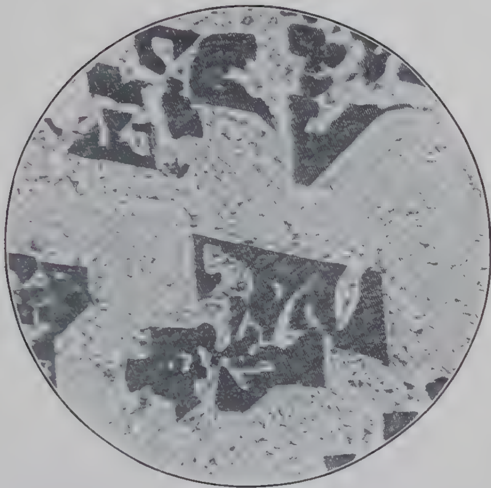
Alloy No. 9. Lead Telluride and Eutectic.
(80 Diameters.)

Fig. 9.



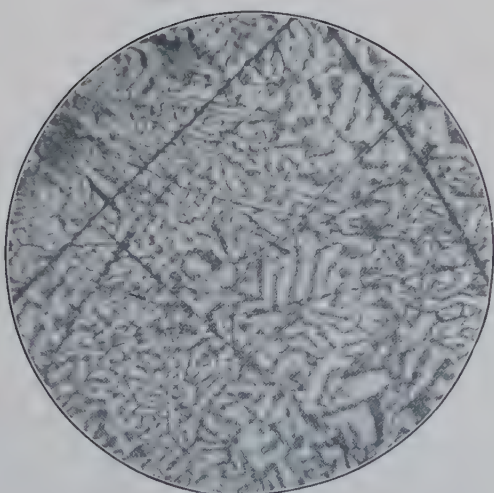
Alloy No. 10. Lead Telluride and Eutectic.
(80 Diameters.)

FIG. 10.



Alloy No. 11. Lead Telluride and Eutectic.
(80 Diameters.)

FIG. 11.

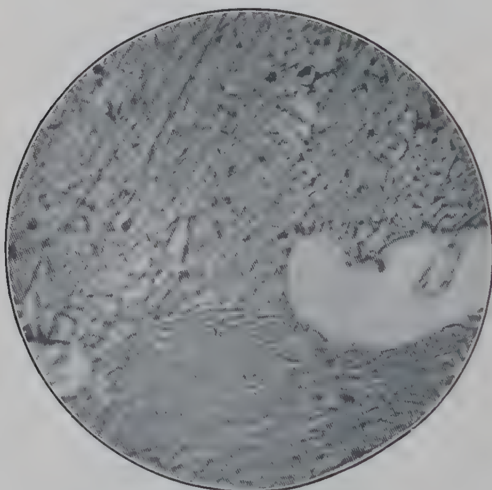


Alloy No. 13. Pure Eutectic.
(80 Diameters.)

per cent. of tellurium. This alloy is the eutectic of lead telluride and tellurium. The four alloys, Nos. 9, 10, 11 and 12, all showed two points of solidification corresponding to the separation of lead-telluride and the eutectic alloy. The eutectic was prepared in pure condition by allowing alloy No. 11 to solidify partially, and then pouring off the portion remaining liquid. An alloy prepared in this way gives a constant melting-point of 400° C., and shows under the microscope the characteristic eutectic structure shown in Fig. 11.

With increase in the amount of tellurium beyond the eutec-

FIG. 12.



Eutectic and Tellurium.
(80 Diameters.)

tic point, the freezing-point gradually rises to that of pure tellurium, 446° C. The freezing-point of tellurium is variously given from 452° to 525° C., but 446° C. has been repeatedly determined on samples, the purity of which was almost beyond question, since, by reason of the method of their preparation, they could not have contained more than mere traces of impurities.

The Microstructure of the Alloys.

The structure of the alloys strongly confirms the curve of fusibility. In Fig. 5, constructed from data obtained from the fusibility-curve, the composition of any alloy can be seen at a

glance. In Fig. 4 it will be seen that the branch of the curve which connects the melting-points of pure lead and lead telluride represents a mixture of lead and lead telluride. The branch connecting the melting-point of lead telluride and the eutectic represents a mixture of these two constituents; the branch from the eutectic point to pure tellurium, a mixture of tellurium and the eutectic alloy. From Fig. 5 the percentage-composition of each constituent can be ascertained. For instance, alloy No. 4, melting at 743° C., contains 32 per cent. of lead telluride and 68 per cent. of lead. This is shown well in Fig. 6, where the light constituent is lead and the dark is lead telluride. With 38 per cent. of tellurium, the whole mass should consist of lead telluride: and this is shown in Fig. 7, from a photograph of alloy No. 8. The effect of an increase in the amount of tellurium we find in alloy No. 9 (80 per cent. of lead telluride, and 20 of the eutectic). This is nicely shown in Fig. 8, where a small amount of the eutectic has made its appearance between the large granules of lead telluride. Fig. 9 represents a photograph from alloy No. 10, containing 46 per cent. of eutectic and 54 of lead telluride. The latter is shown as dark crystallites imbedded in the eutectic. Alloy No. 11 consists of 68 per cent. of eutectic and 32 per cent. of lead telluride. A mixture of these two substances in this proportion is shown in Fig. 10. Fig. 11 shows a photograph taken from the pure eutectic, made by allowing about two-thirds of one of the alloys to solidify, and then pouring off the still liquid mass. A mixture of the eutectic and an excess of tellurium is shown in Fig. 12. The photographs do not represent exactly the percentages of each constituent, but only approximately. On account of the lead telluride being much lighter than lead, a marked segregation was found in the alloys composed of these two constituents. Lead telluride and the eutectic have nearly the same specific gravity, and consequently show a more homogeneous structure.

It will be seen from the photographs, and from the diagram, Fig. 5, that lead telluride is a constituent common to all of the alloys. Its amount gradually increases, as tellurium is added to lead, until the whole mass is lead telluride, and then it gradually decreases until the whole mass is pure tellurium. Tellurium forms a eutectic alloy with lead telluride; but the latter does not form a eutectic alloy with lead. The form of the

curve seems to indicate an isomorphous mixture between lead and lead telluride; and the microstructure of the alloys very low in tellurium seem to point in the same direction. But the two constituents differ so widely in fusibility that there is no definite means of knowing whether or not they are really isomorphous. The isomorphism of these two substances seems all the more probable when we take into consideration the fact that the mineral, altaite, PbTe, crystallizes in the isometric system; and it is well known that lead crystallizes in that system.

The hardness of the alloys increases with the amount of tellurium present. The alloys containing over 50 per cent. of tellurium are very brittle.

It is proposed to continue this study with other tellurium-alloys.

The Alloys of Antimony and Tellurium.

BY HENRY FAY AND HARRISON EVERETT ASHLEY, MASS. INST. OF TECHNOLOGY, BOSTON, MASS.

(Mexican Meeting, November, 1901.)

THE study of an entirely new series of alloys may be undertaken from a desire to obtain knowledge applicable to the perfection of industrial alloys, or merely to test certain theoretical considerations. In the case of antimony-tellurium alloys, the theoretical side only is at present important; but it is hoped that the results of this investigation may have some industrial value, at least indirectly, by furnishing one more example for comparison when studying commercial alloys.

The statement is found in various places that antimony is isomorphous with arsenic, bismuth and tellurium; but very little experimental evidence has been offered in support of this assumption. All four metals crystallize in rhombohedra, and the ratio of the axes $a:c$ is approximately the same—which seems to indicate, but does not prove, their isomorphism. The close association of these metals in minerals also seems to indicate that they are isomorphous. There are, however, certain differences in their properties which render this conclusion somewhat doubtful, and it is therefore desirable that inde-

pendent evidence be found to decide the question. In a paper on lead-tellurium alloys,* it has been shown that two metals which are isomorphous give, as a fusibility-curve, a straight line connecting their melting-points. The best examples of this class of alloys are the alloys of gold and silver, gold and platinum, and bismuth and antimony. In each of these cases the properties of the alloys are a mean between the properties of the two metals. The isomorphism of gold and silver and bismuth and antimony might be confirmed by means of the microscope, but, so far as we know, no work has been published on this side of the problem. The microstructure of binary alloys of isomorphous metals should show an intimate mixture of the two metals without any evidence of compounds or of a eutectic mixture. In connection with some work on the isomorphism of selenium and tellurium we had occasion to prepare several bismuth-antimony alloys, in which we found the microstructure to consist of a very homogeneous mixture of the two metals.

It was hoped that by taking advantage of the fusibility-curve which could be established by determining the freezing-points of a series of alloys, and by a study of the microscopical appearance of etched specimens of these alloys, we might be able to form some idea in regard to the isomorphism of tellurium and antimony.

With regard to the more practical side of the problem, it might be said that tellurium and antimony are so similar in their physical properties that the former might replace antimony in some of its alloys. If this should be found possible, it would open up a field of usefulness for the large quantities of tellurium which now go to waste. The effect of even small quantities of antimony on malleable metals, such as copper and gold, is most injurious, making them hard and brittle; but, on the other hand, it gives the necessary hardness to the lead of type-metal, and produces valuable alloys with tin in Britannia metal for decorative objects, and, with tin, zinc and copper, Babbitt metal for bearings. With lead, its 12 per cent. alloy, the eutectic mixture of these two metals, possesses valuable properties, and is used, on account of its power to resist the action of sul-

* "The Alloys of Lead and Tellurium," by Henry Fay and C. B. Gillson. Present volume, p. 527.

phuric acid, for making the so-called "lead chambers" for the manufacture of that acid.

Tellurium likewise possesses the power of hardening other metals. This hardening power is very marked in the alloys with lead, and Roberts-Austen has found that it diminishes the tenacity of gold and copper. So far as we know, no ternary alloys containing tellurium, and corresponding to Britannia or Babbitt metals, have been prepared.

Methods and Apparatus.

In order to study the properties of the tellurium-antimony alloys, sufficient of each metal was taken to form a button weighing about 20 grammes. In all, fifteen alloys were made, varying from 5 to 95 per cent. of tellurium.

The antimony used was the so-called chemically pure metal, which was found to contain traces of lead and sulphur. Its freezing-point* was 624° C., and its specific gravity 6.693.

The tellurium was obtained from the residue of the Baltimore Copper Works, and was purified by the method described (*ante*, p. 532) in the paper above referred to. Its freezing-point was 446°, and its specific gravity 6.243.

The mixed metals were put in a porcelain crucible, covered with powdered charcoal, fused over the blast-lamp, and allowed to stand until cold. No heat-phenomena were noticed during the melting of the two metals.

From the button thus formed a section was sawed out for microscopic examination, and the larger of the remaining portions was used for a specific-gravity determination. The two larger parts were then united and used for the freezing-point determination.

Freezing-temperatures of the alloys were measured by means of a thermo-electric junction in connection with a galvanometer of the d'Arsonval type, made by Keiser and Schmidt, of Berlin, and so arranged that readings could be taken by means of a needle passing over a graduated scale. This type of instrument was found to be not nearly so satisfactory for experimental work as a delicately adjusted reflecting galvanometer.

* This freezing-point does not correspond to the value, 630° C., recently determined by Holborn and Day; but the slight difference may be explained by the small amount of impurity in our antimony, and by the lag in the galvanometer.

There was considerable lag in the instrument, which could only be obviated by constant tapping; and even by this method we were not sure that our results were correct within five degrees. The pyrometer was calibrated against the following substances:

	Deg. C.		Deg. C.
Boiling water, . .	100	Freezing aluminum, . .	660
Boiling naphthalene, .	218	Freezing gold, . . .	1072
Boiling sulphur, . .	445		

In order to protect the junction from alloying with the vapors of antimony and tellurium, the two wires were passed through two very small hard glass tubes, and these tubes were then placed in a larger piece of hard glass tubing of about 5 mm. diameter.

Freezing-Points.

To determine the freezing-points, the alloys were placed in a Battersea annealing-cup, and were heated to about 100 degrees above their melting-point. The molten mass, protected from oxidation by a layer of finely divided charcoal, was thoroughly stirred, to insure complete admixture of the constituents. The junction was placed vertically in the alloy, and readings of the galvanometer were taken every ten seconds, until the temperature had fallen to 100°. The beginning of the various points of retardation was taken as the freezing-point. The results of these determinations are given in Table I., and are shown graphically in Fig. 1.

TABLE I.—*Freezing-Points of Antimony-Tellurium Alloys.*

Alloy. No.	Antimony. Per cent.	Tellurium. Per cent.	Higher Freezing-Temp. Deg. C.	Lower Freezing-Temp. Deg. C.
1	100	0	624	......
2	95	5	623	......
3	90	10	599	......
4	80	20	568	......
5	75	25	547	......
6	70	30	551	......
7	60	40	561	......
8	50	50	599	......
9	38.63	61.37	629	......
10	30	70	613	422
11	20	80	526	419
12	15	85	434	422
13	10	90	421	......
14	5	95	456	......
15	0	100	446	......

It appears from Fig. 1, in which ordinates represent temperatures and abscissæ percentage-composition, that the antimony-tellurium alloys belong to the class in which occur one or more definite chemical compounds, and in this respect are similar to the lead-tellurium alloys. The compounds in this class of alloys are always indicated by a maximum point in the fusibility-curve, and by a uniform field when examined under the microscope. In this case it will be seen that the maximum point in the curve corresponds to a freezing-point of 629°, and a composition of 61.37 per cent. of tellurium and 38.63 of antimony, which indicates the compound Sb_2Te_3. This compound, antimony telluride, forms with tellurium a eutectic alloy containing 87 per cent. of tellurium and melting at 421°, and is isomorphous with antimony, consequently does not form a eutectic with it. This latter fact places the antimony-tellurium alloys in the sub-class of the third general class of alloys in which one of the compounds is isomorphous with one of the elements. The portion of the curve which connects the freezing-points of antimony and antimony telluride is approximately a straight line, and, considered by itself, represents an isomorphous mixture.

In that part of the curve, which is included between 38 and 100 per cent. of antimony, we should expect to find, and do find, homogeneous mixed crystals of the pure antimony and antimony telluride. The microscopic field between these two points for all alloys examined is very similar, except where the percentage of antimony is very high, in which case there is some tendency for the telluride to segregate out in masses.

The isomorphism of these two substances seems all the more probable, when we consider the fact that the mineral tetradymite, Bi_2Te_3, crystallizes in the rhombohedral system. It is more than likely that the antimony telluride, if it occurred as a mineral, would likewise be found to crystallize in that system. Although tellurium crystallizes in the hexagonal system also, its cleavage indicates that it is not isomorphous with antimony, and consequently not with antimony telluride.

The question might arise as to the existence of a compound of the composition corresponding to the formula SbTe. All we can say at present is that there is no evidence in favor of

such a compound. There are no *a priori* reasons why it should not exist, and it is entirely possible that it should exist and form an isomorphous mixture with antimony and antimony telluride Sb_2Te_3. If it were formed in this mixture, we should expect a more marked evolution of heat in the alloys corresponding to this composition; but the amount of heat evolved in the alloy corresponding to this composition was not above the average for the other alloys.

Oppenheim* makes the statement that antimony forms either iron-gray SbTe, or tin-white Sb_2Te_3. The only evidence, however, in favor of the compound was that the iron-gray mass was homogeneous and had cleavage-planes. The assumption seems to have been based on a very small amount of evidence; for the result of our work shows that with these proportions an alloy is formed which, although brittle, homogeneous and crystalline, is merely an isomorphous mixture of antimony and antimony tritelluride.

From an inspection of the freezing-point curve it seems to be evident that antimony and tellurium are not isomorphous, as has been generally supposed, and that consequently they do not mix at the temperature of fusion as such. On the contrary, tellurium and antimony telluride form a series of alloys which in all respects is similar to the class of alloys of which the lead-tin and silver-copper alloys are good examples. In other words, the freezing-point of either antimony tritelluride or of tellurium is lowered by the presence of the other, no matter which one we consider as the solvent. They are mutually soluble, and mix in all proportions.

Percentage-Composition of the Constituents.

To express approximately the composition of any particular alloy, a diagram, Fig. 2, has been constructed, which will show at a glance the percentage of each constituent. The abscissæ represent the percentages of antimony and tellurium, and the ordinates the division of the total 100 per cent. of the alloy into percentages of tellurium and eutectic alloy, antimony telluride and eutectic alloy, or isomorphous mixture of antimony

* *Jour. f. Prakt. Ch.*, 1857, 71, 277.

and antimony telluride. For instance, an alloy whose chemical composition is 40 per cent. Te and 60 per cent. Sb is made up of a mixture of 35 per cent. antimony and 65 per cent. antimony telluride. Again, if we wish to obtain an alloy containing 34 per cent. of eutectic and 66 per cent. of antimony telluride, it is readily seen that it must consist of 70 per cent. of tellurium and 30 per cent. of antimony.

Specific Gravities.

In view of the nature of these alloys, it was thought desirable to study the specific gravities; but from the results obtained no conclusion could be drawn. It seems to be true that nearly all the physical properties of alloys are additive, and give no clue to the nature of the constitution. Various values for the specific gravity of tellurium have been given. Rammelsberg found for the amorphous variety the value 5.93 and for the crystalline 6.38 to 6.42. At 0°, Spring* found for the uncompressed, 6.2322, and for the compressed, 6.2549. Later, he reported the value 6.22. Klein and Morel† found values varying from 6.204 to 6.215; and recently Lenher and Morgan‡ have reported the value 6.1993. Priwoznik§ obtained the value 6.2549 on a specimen which had been carefully prepared, and which had been fused in a current of hydrogen.

Using a specimen of tellurium which had been prepared from recrystallized basic nitrate, we found the value 6.243. This value represents several actual determinations on specimens known to be pure and free from blow-holes, and is also the average of several other determinations on other specimens. The most accurate determination was made from a button weighing from 30 to 40 grammes, which had been fused several times under charcoal. This was split in half, and the outside surfaces were smoothed on an emery wheel. It was suspended in boiling water for some time; the water was allowed to cool, and this button of 18.64 grammes was weighed in water and in air. As great care had been taken to remove all traces of silica and selenium, these two sub-

---

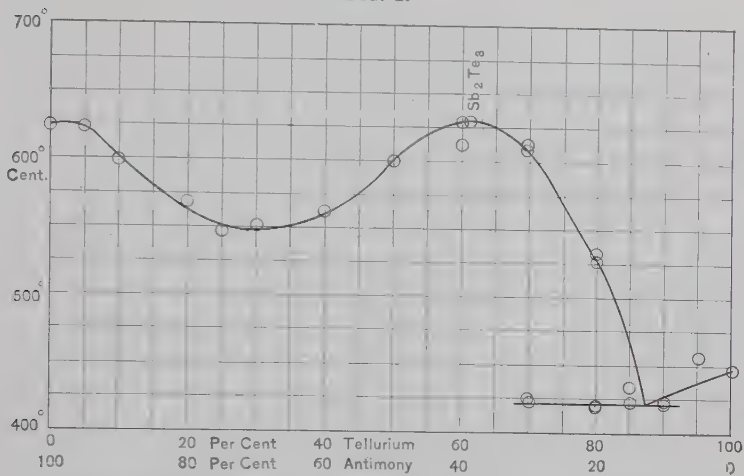
* *Bull. Acad. Royal Belgique*, 5, 854.

† *Bull. Soc. Chim.*, [2], 43, 198.

‡ *J. Am. Chem. Soc.*, 1900, 22, 29.

§ *Chem. Cent.*, 1892, ii., 962.

FIG. 1.



Freezing-Point Curve of the Alloys of Antimony and Tellurium.

FIG. 2.

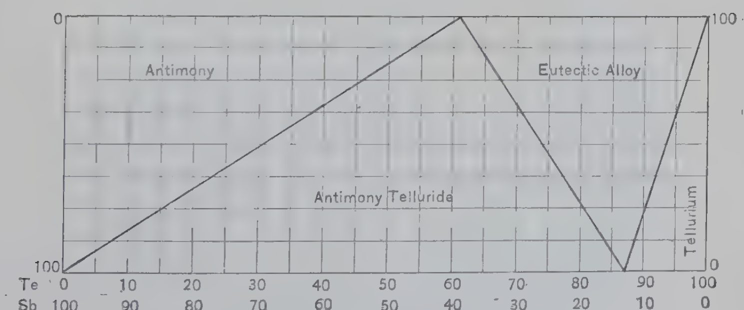
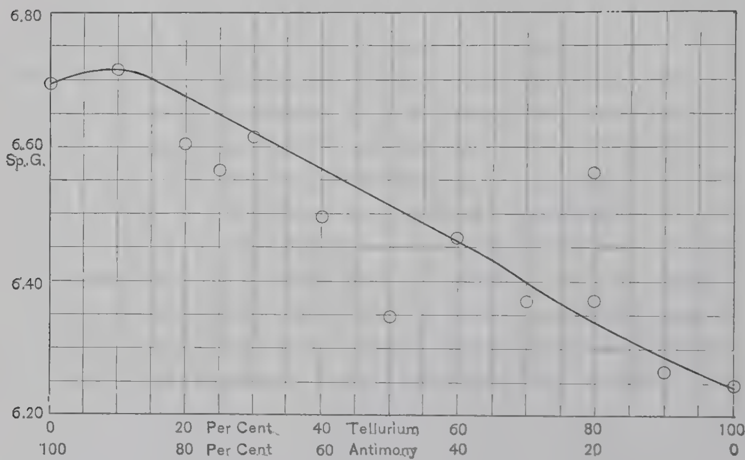


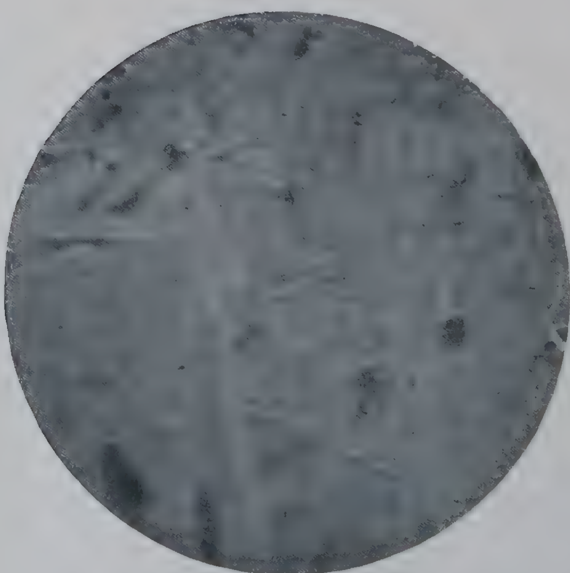
Diagram Showing Composition of Constituents of the Alloys of Antimony and Tellurium.

FIG. 3.



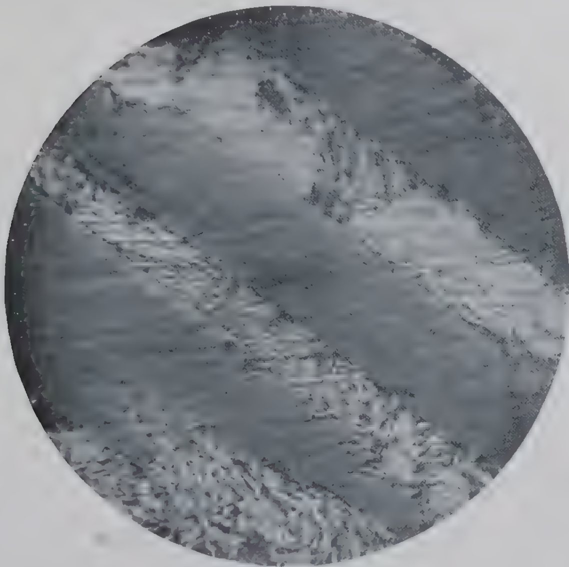
Specific Gravity Curve of the Alloys of Antimony and Tellurium.

FIG. 4.



Alloy No. 9. The entire field consists of Antimony Telluride, Sb_2Te_3. (Magnified 95 diam.)

FIG. 5.

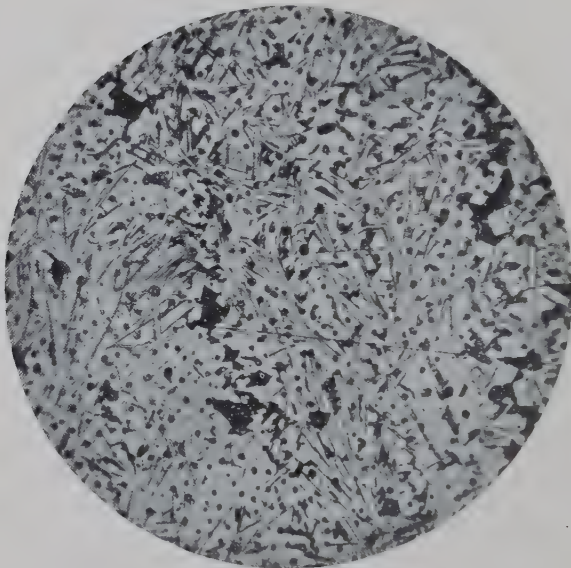


Alloy No. 11. Dark, crystallites of Antimony Telluride; light, eutectic of Antimony Telluride and Tellurium. (Magnified 95 diam.)

FIG. 6.

Eutectic Alloy. Slowly cooled; etched with Hydrochloric Acid. (Magnified 95 diam.)

Fig. 7.



Eutectic Alloy. Cast on porcelain; unetched.
(Magnified 95 diam.)

Fig. 8.

Alloy No. 15. Light, pure Tellurium; dark, eutectic of Tellurium and Antimony Telluride. (Magnified 95 diam.)

stances could not have affected the results. The greatest sources of error are blow-holes, to which the extreme crystalline character of the metal makes it liable, the inclusion of oxide, and the presence of heavier metals. We have reason to believe that by our method of preparation these factors were avoided.

The specific gravity of antimony telluride is given by Bödeker and Giesecke as 6.47 to 6.51 at 13°. For the alloy containing 60 per cent. of tellurium we obtained 6.46. The results for the other alloys were, as a whole, very unsatisfactory, and the values given in the following table are only approximate. Some of the alloys were so crystalline that it was impossible to obtain them free from air-spaces. In certain cases, large drusy cavities were found in the center of an ingot after weighing. This tendency to form inter-crystalline cavities was especially marked in the alloys containing from 0 to 40 per cent. of tellurium. Beyond this point there was a tendency for the eutectic alloy to fill up these spaces, as is shown in Fig 5, where the eutectic has flowed in between the long, parallel crystals of antimony telluride. The crystals in this case are colored dark on account of superficial oxidation, but ordinarily are almost silver-white.

TABLE II.—*Specific Gravities of the Alloys of Antimony and Tellurium.*

(Shown graphically in Fig. 3.)

Weight of Specimen. Grammes.	Tellurium. Per cent.	Specific Gravity.
18.6462	100	6.243
6.1011	90	6.264
0.703	80	* 6.56
0.941	80	* 6.17
3.681	80	* 6.370
6.201	70	6.370
5.4491	60	6.462
8.9995	50	6.347
3.8007	40	6.496
4.2680	30	6.615
7.7445	25	6.564
6.4322	20	6.601
2.5014	10	6.717
12.3573	(Pure antimony.) 0	6.693

* Three specimens from one ingot.

As the percentage of tellurium approaches the amount necessary for the eutectic alloy, the structure is somewhat micaceous, some of the planes of fracture showing a matte surface. This micaceous structure is responsible for a turning over of edge, and is very evident when one attempts to pulverize a piece in a mortar. Most of the other alloys show a remarkable crystalline cleavage, the surfaces of which are very brilliant.

Both antimony and tellurium, and all their alloys, have approximately the same degree of hardness, somewhat above 2.5 (mica) and decidedly lower than 4 (fluorite). From 0 to 20 per cent. of tellurium, the alloys closely resemble antimony.

Microscopical Examination of the Alloys.

The preparation of satisfactory samples for microscopic examination proved to be very difficult. On account of the highly crystalline character of some of the specimens, there was a great tendency for small fragments to split out along cleavage-planes, thus leaving a pitted surface. By careful treatment, a fairly satisfactory surface could be obtained by first rubbing on an oil-stone under water, then polishing lightly on a wheel with a mixture of rouge and stearic acid, and finally on a piece of chamois stretched on a wooden block.

The process of etching was likewise difficult. Hydrochloric and nitric acids and iodine were all used without any appreciable effect. The best results were finally obtained by electrolysis in either dilute hydrochloric acid or ammonia. The specimen to be etched was attached to one of the poles of a battery, and a current of about 0.1 ampere was allowed to pass for a few minutes. The structure was brought out by this means; but there was considerable superficial oxidation which produced beautiful colored effects on the surface. This darkening effect is well shown in Fig. 5, where the crystals of Sb_2Te_3 have branched out through the eutectic alloy. Before etching, the whole surface was brilliantly white; but after etching, the crystals were colored a beautiful blue, which in some cases revealed the structure to the naked eye. The alloys from 0 to 60 per cent. of tellurium were all richly colored, and showed under the microscope a uniform crystalline field with the single exception of the alloy containing 5 per cent. of tellurium

which was composed of rounded granules of antimony telluride, imbedded in pure antimony. A cross-section of any of these alloys showed branching crystals extending from the bottom to the top of the ingot.

The alloy containing 61.37 per cent. of tellurium presented an absolutely uniform appearance, being composed entirely of the compound Sb_2Te_3, and is shown in Fig. 4. The dark spots in the photograph show the cavities produced as a result of the crystallization. With an increase in the percentage of tellurium beyond this point, the eutectic alloy of antimony telluride and tellurium began to show. In alloy No. 11, Fig. 5, this is shown very clearly. In this alloy long crystallites of antimony telluride appear throughout the mass, and the space between the separate crystals is filled with the eutectic. In this case the crystals are dark, on account of the superficial oxidation produced in etching.

Figure 6 shows the appearance of the eutectic alloy, as it was usually found in the alloys containing from 60 to 90 per cent. of tellurium. In slowly cooled alloys the structure was invariably the same, but more rapid cooling produced an entirely different appearance. Figure 7 represents a photograph of the pure eutectic, prepared from several other alloys by pouring off the still liquid mass after a part had solidified. The photograph represents a surface which had been cast on glazed porcelain, and was taken just as it appeared after cooling, without any further treatment. The light background is tellurium, and the dark portions are antimony telluride. The latter was probably brought out in such great contrast on account of its extreme tendency to oxidize.

Figure 8 shows the usual appearance of the alloys consisting of the eutectic and an excess of tellurium.

It is proposed to study in the same manner other binary alloys of tellurium, and subsequently some of the ternary alloys.

Recent Geological Phenomena in the "Telluride Quadrangle" of the U. S. Geological Survey in Colorado.

With Special Reference to the Report of Messrs. Cross and Purington upon that Area.*

BY H. C. LAY, TELLURIDE, COLO.

(Mexican Meeting, November, 1901.)

No one who knows the conditions of altitude, difficulty of access, shortness of working-season, etc., under which the work of the U. S. Geological Survey in the Rocky Mountains is carried on, can fail to be impressed with the magnitude and accuracy of the results obtained. Yet, in the necessarily brief time given to any one district, many minor features must remain unregistered. The purpose of this paper is merely to place on record observations, made during nearly eighteen years, of local phenomena in themselves unimportant, which, however, if collated with similar memoranda from neighboring regions, may lead to something of value.

The Telluride quadrangle in southwest Colorado is a tract of fifteen geographical minutes on a side, the NW. corner of which is in Long. 108° W., Lat. 38° N. Topographically it is essentially a lofty horseshoe, some of the peaks of which rise more than 14,000 ft. above tide, the interior (with an average altitude of 9000 ft.) being the eastern edge of the rolling Colorado-Utah plateau, and, in its turn, deeply cut by the cañons of the San Miguel river and its tributaries.

The range-summits are mainly igneous rocks, partly intrusive (such as massive "stocks" and laccolites, left bare by superior erosion), but mostly bedded volcanics of an average vertical thickness of 3500 ft., which change with changing height from andesite to rhyolite. The lowest series of these volcanic rocks, known as the San Juan formation, lies conformably upon the sedimentary San Miguel conglomerate, which dips gently east, and is attributed provisionally to the

* *U. S. Geol. Survey*, Telluride Folio (No. 57), 1899.

Eocene. Below the conglomerate are the Cretaceous and the Jura-Trias, dipping westerly.

It is thought (*Telluride Folio*, p. 1) that the whole region is still rising.

Glacial Phenomena.

The report cited (p. 15) says that the glacier of the South fork of the San Miguel river, when at its maximum, more than filled the cañon: that, east of its junction with the valley of the main river, there was no corresponding contemporaneous ice-stream; and that consequently a lake was formed by this enormous dam. No cause is suggested for the unlike conditions in the water-sheds; but correctness of the hypothesis is proved by the still existing spill-way, so to speak, of the former lake.

Directly opposite the mouth of the South fork, on the north side of the main cañon (here 1000 ft. deep), stands a somewhat projecting cliff, capped with Dakota sandstone, which must have been what we may call the abutment of the ice-dam. At the easterly end of the cliff, the old river-bed, some 60 ft. wide and 30 ft. lower than the crest, swings northward out of the main valley, and, after running parallel thereto for 700 or 800 ft., turns southward and debouches in the rim-wall of the cañon, thus showing the probable height and width of the glacier at this point.

The question has been asked, whether it would not be worth while to prospect this channel for placer-gold; but, in view of the effect of the lake above, in permitting suspended gold to settle to the bottom, the occurrence in this place of such deposits seems in the last degree unlikely.

On the same page of the report cited, the present existence of *névé* ice is mentioned, and the remark is made that a late and but slight change in climatic conditions has occurred since the higher basins were perpetually ice-filled. This margin is but narrow, even now.

In this connection, the following observations are of interest:

Early in September, 1888 (the 3 or 4 years preceding having been marked by unusual cold and snow-fall), *névé* ice was found on the La Rosa lode (altitude, 12,300 ft.) at the north foot of

San Joaquin Mt., entirely covering workings that had been driven less than 8 years before.

At high altitudes, a large part of the district is, beneath the surface, still in a condition of glacial cold. This is, naturally, most plainly exhibited on northern exposures.

On the Montana No. 2 lode (altitude, 12,200 ft.), on the middle fork of Marshall Basin, a shaft, 115 ft. deep, in disintegrated or "slide" rock, passed out of ice only five or six feet before attaining the depth stated, in a solid formation. Here the surface receives some sunshine at all seasons.

At the North Chicago mine (altitude, 12,900 ft.), not within the limits of the report cited, but a mile east of the Columbia mine, a horizontal adit, in a slope facing NW., has been driven through wash 225 ft. (gaining a depth of about 100 ft. below the surface) to the solid rock-outcrop. Here a shaft, sunk on a vein with average dip of 72°, does not pass out of ice for 160 ft., or more than 250 ft. below the surface. The ground NW. of the adit-mouth is comparatively flat; and there is but little sun in winter.

The Gold King vein cuts SW. through the E. and W. ridge of Silver Mt., most of its levels passing entirely through the divide. The lowest of these open levels (altitude, 11,800 ft.), which is 1200 ft. long, showed frost, when last observed, for 500 ft. from the northerly entrance.

The mines on the north side of the Mt. Wilson group strikingly show this constant low temperature, which causes much difficulty in the storing of mine-supplies underground.

In the main level of the Silver Pick (altitude, 13,000 ft.) a vein of ice was found 1200 ft. from the mouth, so firm and clear that the foreman mistook it at first for quartz. At this point the vein must be vertically 500 ft. underground; and the nearest surface-point at the same elevation is 400 ft. away and almost sunless.

In the Special Session and Southport workings (altitude, 13,200 to 13,500 ft.), adjoining the Silver Pick on the west, the walls are completely covered with delicate acicular ice-crystals, sometimes two inches long, the exquisite brilliancy and beauty of which far surpass those of any limestone cavern.

The persistence of glacial cold at the Southport mine is very

remarkable. At this place, the E. and W. divide is only 7 or 8 ft. wide, with 45° slopes; yet a tunnel 80 ft. long, of nearly parallel direction, practically under the crest, and only 30 or 40 ft. lower, is in perennial frost, though the sun beats fiercely on the S. side of the mountain, less than 50 ft. away.

Not long since occurred an opportunity to note the rate of formation of ice under such conditions as have been described. At an altitude of about 12,000 ft. a 60-ft. shaft was sunk through "slide" to bed-rock, and a short drift was run from the bottom. The work was stopped about the middle of August, and several feet of surface-water had accumulated in the excavation before it was unwatered, early in November. At the latter time the sides and bottom of the drift were found to be covered with ice about 5 in. thick, and (from evenness of temperature) so clear that, with but one candle, the characteristics of the adjacent rock could be seen as plainly as if nothing intervened. In the shaft proper, probably on account of varying temperature, the ice was less transparent and irregular in thickness.

Earth-Movements.

Land-Slides.—The importance of geologically recent earth-movements in the Telluride region may be inferred from the fact that the area of a single land-slide within the quadrangle is about ten square miles.

Great good has been done by the report under consideration (pp. 10, 11 and 15) in calling public attention to the significance of these movements. On one property alone, which was situated in a land-slide tract, the previous outlay must have amounted to a considerable proportion of the total cost of the Report. Upon its publication, work upon that property was indefinitely suspended, and further fruitless expenditure was avoided.

The tract lying between the Elizabeth and Ballard mines, in the bedded San Juan volcanics, on the W. slope of Ballard mountain, has been apparently the scene of unusual disturbance, continuing to a recent date. By what was probably the last movement, the cliffs were split downward for 60 or 70 ft., and large blocks were broken from their sides, the edges of which are as sharp as if the fracture had taken place but yesterday. The earlier of these movements may have been caused

by land-slides alone; but as the more recently formed crevices are nearly vertical, and do not exceed 10 ft. in width, their most likely origin was the short, quick blow of an earthquake.

On the W. side of Bear creek, in the same series, immediately E. of the N. and S. Stargazer vein (itself, perhaps, a factor in the movement), may be observed the trough-like depression of a land-slide and fault, extending nearly a quarter of a mile S. from the E. and W. Nellie-Ella vein. Wherever not covered by *talus*-slopes, the hillside below this hollow shows general dislocation. It is at least possible that this disturbance is remotely connected with the occurrence of the San Miguel conglomerate just beneath the surface of the valley below, and more directly with an upheaval or subsidence by which the beds of the two branches of Bear creek, which formerly ran parallel, and presumably at the same level, for a mile north of their present junction, were brought to elevations so different as to cause the E. channel to lose its water-supply and, gradually filling up, to become almost obliterated, except where it had cut its way through the conglomerate cliff.

The N. slope of Howard's Fork, like most sunny, grassy slopes in this region, is now so thoroughly covered with the minute terraces, made, since the advent of mining industry, by burros and other beasts of burden, in grazing along the steep hillsides, that other features are relatively obscured.

In view, however, of many slight fissures in the *talus*-slope, and a movement of boulders from a sandstone ledge, to a degree beyond plausible reference to weathering as the cause, there is reason for the belief that a slight yet constant movement, possibly superficial, is now taking place W. of the Winnemucca lode, in the neighborhood of the junction of the Dolores formation with the San Miguel conglomerate.

Though beyond the proper purview of this paper, it may be worth mentioning that at Rico, 20 miles SW. of Telluride, where the sliding is constant, it is reported that carefully fixed surface-points have moved 8 ft. in 6 years, and that the posts in the mine-levels, which are originally set with a cant of 6 inches, gradually rise until they become vertical, when they are replaced by others, having the former inclination.

Earthquakes.—While the earthquakes in the San Juan country since the visits of white men (and before, so far as

Indian tradition goes) have been in themselves insignificant, yet, in all likelihood, they have had indirectly much influence in the bringing about of land-slides, as pointed out by Mr. Cross—proximately, by the jar of the shock; and, less immediately, by the liberation, or direction into new channels, of subterranean waters.

The most important earthquake, so far as known, in the San Juan region, occurred Jan. 1, 1894, and was generally observed in the neighborhood of Telluride. In the town from one to three shocks were felt (possibly according to the varying comparative ease with which different observers were aroused—although one person, already awake, noticed but two). It is generally agreed that there was a shaking of beds, a swinging to and fro of hanging lamps, and other such movements, with a noise like that of a distant stamp-mill; that the shocks were of two seconds' duration (which is, of course, impossible under the circumstances), and that the second shock was heavier than the third, and came half a minute earlier. One close and very accurate observer, who fortunately chanced to be wide awake, says:

> "It was at 3 A.M. There were three distinct shocks, very short, following in quick succession, and occupying in all, I should say, less than a minute. The sensation was that of the bed being lifted and shaken. I thought the wave came from a little N. of E. In the second story (of a frame-building) the vibratory motion was more perceptible, and the pictures swung about."

The town of Telluride stands on gravel, several hundred feet deep, the adjacent (and probably subjacent) formation being the Dolores series of sandstones, shales and conglomerates, which is the lowest local member of the Jura-Trias.

In the igneous rocks there were some anomalies; the earthquake does not seem to have been perceived through the "stocks," or manifested to the W. of Telluride; while in the bedded volcanics it was generally observed on the surface, locally, and also at Red Mountain, 6 miles E., and hence in the direction from which the wave is said above to have come. Red Mountain is nearer the supposed former focus of volcanic activity and has been the scene of much solfataric action.

Underground there were considerable differences of force. At Red Mountain (altitude, 11,000 ft.) the miners fled tumul-

tuously from the workings of the Guston, Yankee Girl and other mines, while on the Telluride side, with one exception, they did not observe the shock, or else paid no attention to it.

In the adit- or lowest surface-level of the Sheridan mine of the Smuggler-Union Company, in Marshall basin, the miners, who were about 2000 ft. from the mouth, and 600 ft. below the surface, were driven out; while the only other men anywhere near them, in level No. 2, which was 170 ft. higher and nearly overhead, were not disturbed.

It is interesting that this adit-level (altitude, 11,900 ft.) coincides very nearly with the division between the andesitic tuffs and breccias of the San Juan formation, and a superincumbent massive augite-andesite which forms the lowest member of the "Intermediate Series" of Messrs. Cross and Purington's report.

Several hundred men in other workings of the Smuggler-Union mines, from 100 to 1000 ft. below this adit, and from half a mile to a mile further S., noticed nothing of consequence, while a vertical shaft, 660 ft. deep, which had been recently completed, was not affected.

In the succeeding summer, and thereafter, it was remarked in Marshall basin that the flow of streams, both surface and subterranean, especially near the Sheridan, was much smaller than it had been before, and the mines were in consequence much inconvenienced; this diminution, however while unquestionably due in part to the disturbance just described, is also in part a necessary consequence of the deep draining of the *talus*-mounds.

It is greatly to be regretted that it seems impossible to gain any accurate account of the manifestations of this earthquake at Red Mountain, other than that stated above. This paper has been held back for six months, while diligent search was made for some competent observer who could furnish further facts; but no such observer has been found. A "full account," rumored to have been published in a newspaper, remains (if it exists at all) buried in some unknown file. The only additional information I have elicited is, that in that region there were slight shocks at the same hour on the two following nights, and that one person at Ironton, three miles north of Red Mountain, who noticed the occurrence on the third night, says that it came

from the E., and is very positive in the curious statement that he heard the swelling rumble approaching from the E. before he felt the shock.

It is likely that slight earthquakes are more common than is generally believed, escaping notice during the day on account of other noises, and not identified at night because mistaken for distant blasts, or else because not then perceived, by reason of the heavy slumber general in high altitudes.

One resident of Telluride, temporarily out of health during 1897–8, and therefore easily aroused, noticed during that season three shocks, of which the first occurred on Tuesday, Aug. 3, 1897, a little after midnight. Of the other two no date is given; they were noticed only by the person referred to, so far as he is aware. The first of the three was noticed by another person in Telluride, and by one in Ouray. At Ridgway, 15 miles N., in an alluvial valley adjoining the Mancos shale, it was comparatively violent.

According to the Telluride observer first mentioned, who was in the second story of a brick building, the shocks all occurred between 1 and 4 A.M. in summer; and, in connection with each, the same phenomena were observed, namely: a sudden startled awaking, with a feeling of great discomfort, and a slight trembling of the whole building, together with a clear, fine ringing sound, apparently local, and very close at hand, the cause of which was not determinable, while repeated attempts to reproduce it were entirely unsuccessful.

The other Telluride observer, who was in a frame-house, and the Ouray observer, heard also a roaring, rumbling noise.

At Ridgway, animals were frightened and sought their owners; houses rocked slightly; and small objects were thrown from tables and shelves.

Underground Waters.

The report of Messrs. Cross and Purington points out in detail (p. 10) the important part played in the production of land-slides by the percolation of surface-water, through the porous volcanic complex and San Miguel conglomerate, to the sandy Mancos shale, and by the partial plasticity of the last-named thus brought about with each returning spring. In view of this important factor, it seems advisable to give in detail the following instances of subterranean flow.

At the S. end of the narrow divide between Cornet and Butcher creeks, about 1200 ft. above the valley, a hollow pitches steeply SE. to the cliffs of Cornet creek cañon, 200 or 300 ft. N. of the mouth. The winter of 1883-4 was one of great cold and unequalled precipitation, the snow-fall as low as Telluride (altitude, 8800 ft.) having been about 50 ft. Late in May, 1884, at a point in the depression just described, 40 ft. below the ridge-crest, a stream burst forth. So great was the flood that it caused a slight alarm in Telluride: and the sound of its fall was heard two miles away. After the first half-hour, the flow remained about constant for three days: then, gradually lessening, finally ceased in about ten days. No measurements were taken; but the flow of the first three days was at least one cubic foot per second. The quantity of solid matter brought down was insignificant, and there has been no recurrence of the flow at that exact point; although a visit to the spot in 1900 showed that, probably in the preceding spring, a small outburst had occurred a few hundred ft. to the SW. The watershed is too small for any permanent stream, and snow never lies in that particular place for more than a few days.

The small superficial area of the ridge near the point of appearance of the stream of 1884 is worthy of mention; and still more significant is the fact pointed out by Mr. Cross (*op. cit.*, p. 4), that just here the water-bearing Mancos shale is cut off by the (likewise porous) San Miguel conglomerate, dipping in the opposite direction.

The compact Dakota sandstone, lying immediately and conformably under the shale, is exposed at the point of emergence of the stream by the erosion due to the latter; but elsewhere at this horizon the rocks are covered by surface-soil and *detritus*.

Postscript.

Since this paper was written, the writer has become indebted to Major A. B. Litchfield, manager of the San Bernardo mine, for information of a most interesting subterraneous flood of more recent occurrence.

The Three Sisters lode lies a few hundred feet N. of, and nearly parallel to, the vein of the San Bernardo; its principal working, a 600-ft. tunnel (which cannot be examined since the outburst in question), being about 3000 ft. W. of the Lake fork

of the San Miguel, and 1200 ft. higher, at an elevation of 10,600 ft. The lode lies in the hardened Mancos shale, has a westerly course, and, so far as may be determined from the dump, is a dike from the diorite-monzonite "stock" below. By reference to the maps accompanying Messrs. Cross and Purington's report, it will be seen that this drift passes under San Bernardo mountain at a depth of 1300 ft., the superincumbent mass being entirely Mancos shale, except a small cap of the San Miguel conglomerate; that the drift, prolonged westerly 6000 ft., would strike Wilson Creek valley at about the stream-level: and that, except for a narrow neck half a mile S., and only 400 ft. higher, it is isolated by valleys from any distant flow. A small stream flows perennially from the tunnel-mouth.

The snow-fall since March 1, 1901, has been heavier than in any year since 1884, being estimated at the altitude of the Three Sisters by careful observers, and by comparison with former positive measurements, to have been 40 ft. during March and April—a considerable amount having fallen also during May.

On May 26th, at 3 A.M., there burst forth from the tunnel just described, which is 4 ft. wide, a stream 2 ft. deep, which continued without change till 9 A.M. At noon it was but little lower; in the evening it was 1 ft., and on the 27th at noon still 9 in. deep. It then gradually resumed its usual dimensions, which, on July 3d, were nine inches wide by one and a half deep in a box with a fall of 3 per cent.

As will be readily inferred, the outburst caused a serious erosion of the hillside below, the average slope of which is 25°; and a channel was excavated all the way to the Lake fork of a nearly constant depth of 15 ft., the width varying from 18 to 35 ft. at the top, and from 1 to 5 at the bottom.

The loose rock buried in the *talus* was brought down and redeposited by the stream in its descent, leaving now, on either side of the present ravine, a bed, 20 ft. wide and 2 ft. deep, of angular stones, many of which weigh 70 or 80 lbs.

The ventilating-machinery having been destroyed, the tunnel is now largely filled with bad air, and therefore impassable beyond a point 150 ft. from its mouth.

An Electric-Resistance Magnesia Crucible-Furnace for Laboratory-Use.

BY PROF. HENRY M. HOWE, COLUMBIA UNIVERSITY, NEW YORK CITY.

(Mexican Meeting, November, 1901.)

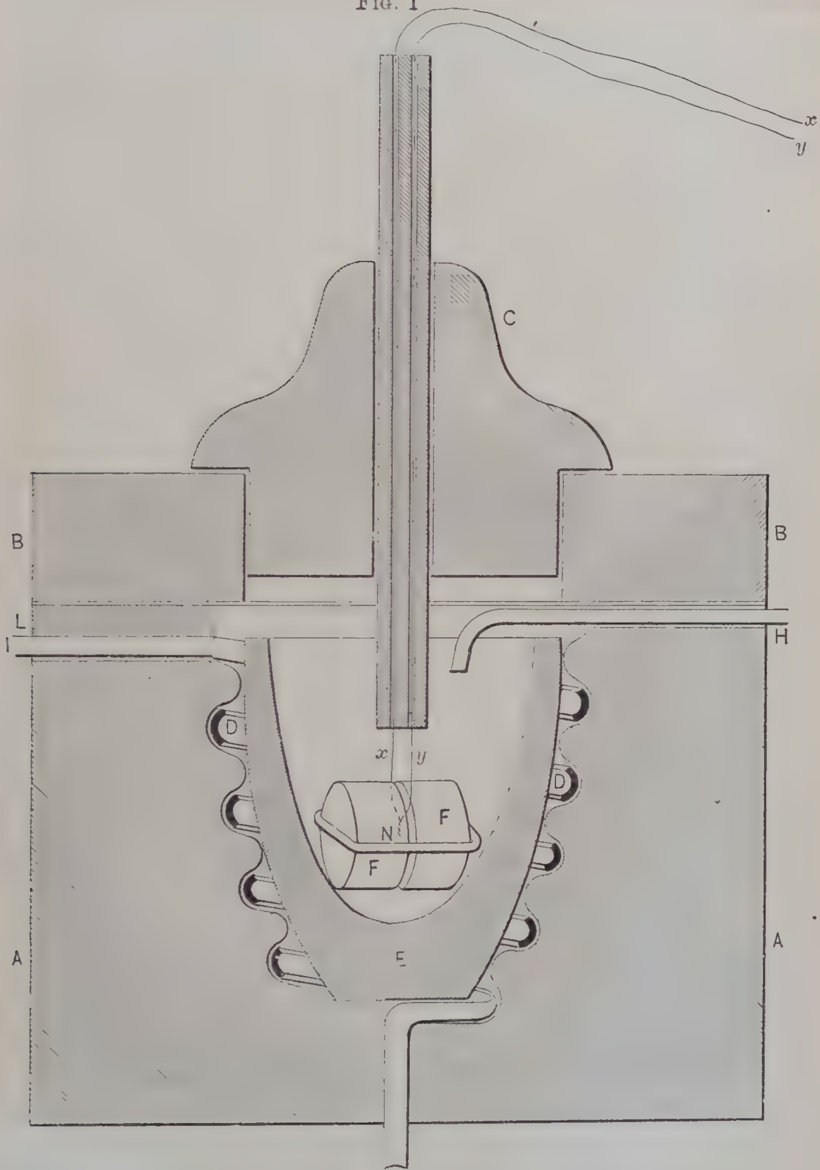
ONE of the little electric-resistance magnesia crucible-furnaces which I designed for the metallurgical laboratory of the School of Mines of Columbia University is shown, in vertical section, of full natural size, in Fig. 1.

The furnace itself consists of two semi-cylinders of magnesia, A A, with a cover of magnesia, B B, and a stopper, C, also of magnesia, which is perforated to admit the leads x, y, of a thermo-electric couple. The furnace is heated by the spiral of platinum wire, D D (entering and departing by the openings I and K), through which a current of any desired strength is passed, bringing it to incandescence, and to any temperature, not above the melting-point of platinum, which may be desired. The crucible E, actually used in this furnace, is also of magnesia.

I have heard of some unsuccessful attempts with furnaces of this general class, and have attributed these failures to the use of siliceous materials for the furnace-walls. Of course such a result is what we should expect, since the silica would readily be electrolysed by the current, and the resultant silicon would alloy with platinum; but the little magnesia furnace here described seems to be wholly free from this objection. It has been used in my laboratory for some months, and temperatures up to 1100° C. have been developed in it over considerable periods of time—indeed, it has been held near 1400° C. for about two hours—without indication, thus far, of any deterioration of the platinum.

In the section shown, F F are a pair of steel disks, bound together, but separated by the inverted thermo-junction, N, of the thermo-electric pyrometer. This arrangement permits the observation and record of retardations in the heating and cooling of F F—in other words, the determinations of the cooling curves of steel—a purpose for which the furnace has been used, thus far, more frequently than in the determination of melting-points. For the latter operation, however, it is also suitable.

FIG. 1



Electric-Resistance Crucible-Furnace. (Vertical Section, Actual Size.)

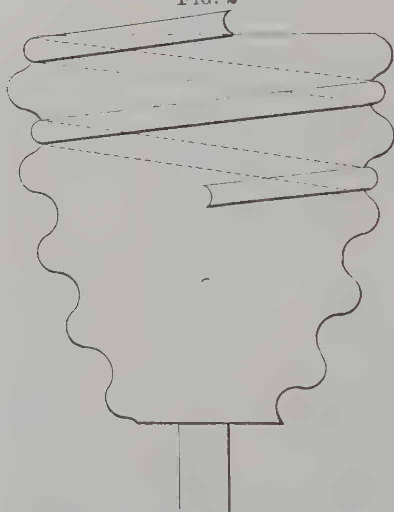
Indeed, it was originally designed for use in calibrating thermo-electric couples by means of the melting-point of copper. For this purpose, the method described by Holman* had been found

* *Proc. Am. Acad. of Arts and Sci.*, 1895–6, p. 240; also *Technology Quarterly*, viii., Oct., 1895, p. 300.

upon repeated trial to be unsatisfactory, because of the liability of the copper to oxidation; and this apparatus was devised to permit the crucible to be filled with an atmosphere composed of equal volumes of carbonic acid and carbonic oxide—a gaseous mixture which does not oxidize copper,* and, at the same time, is unlikely to cause deposition of carbon.

In such an operation, the mixture of carbonic acid and oxide, or any other desired atmosphere, is introduced through the pipe H, which, as well as the openings I and K, may be tightly packed, while the cover, C, is luted on. Absolutely air-tight

FIG. 2



Mandrel Used in Placing the Heating-Coil D, Fig. 1.

closure, however, is not required, since a gas-pressure, through H, sufficient to maintain a *plenum* in the crucible, and to offset small leakages, will be a sufficient prevention of change of the interior atmosphere. As already observed, AA, BB and C are magnesia. L is packing.

Besides the uses described, the furnace lends itself to a great variety of purposes—as, for instance, when it is desired to reach quickly and accurately a desired temperature, or to hold a small object for a long time at a given temperature, and especially when we wish to avoid an atmosphere containing the products of combustion of any fuel.

* This I showed in Oct., 1878 (*Trans.*, vii, 443), confirming Bell's results (*Jour. Iron and Steel Inst.*, 1871, i., p. 98).

In order to increase its radiating surface, the spiral D may be made of a special U-shaped wire, like that employed for the ribs of umbrellas. What we have actually used, however, has been simply a pair of wires of 0.04 in. diameter (No. 14, American wire-gauge), twisted around each other.

To facilitate placing the spiral in its grove within the furnace, I devised the mandrel G, shown in Fig. 2. The mandrel, with the wire wound upon it, is set approximately in place in the furnace; the mandrel is then withdrawn by screwing it to the left: the two halves of the furnace are at the same time pushed together; and the wire is thus fitted into the spiral groove made for that purpose in the furnace-walls.

As to the material of the wire, I am informed that, for temperatures up to 1200° C., nickel wire serves well for heating by resistance. Some of the new high-resistance alloys also should be available for this purpose at moderate temperatures, and would be, of course, much cheaper than platinum. It is reported that platinum volatilizes somewhat rapidly at 1350° C., though without correspondingly rapid loss of ductility. In the use of the furnace here described, we have noticed some indications that platinum had volatilized at or above that temperature. However, if such high heats be prudently avoided, platinum wire should last for years. M. Osmond informs me that, in connection with his thermo-electric pyrometer, he has used for many years one set of such wire. Moreover, when the wire is finally spoiled, it is still platinum, and can be sold as metal, or remelted and redrawn as wire. The objection based on its initial high cost is therefore less formidable than if it were completely consumed in use. Apart from this item of expense (amounting, for the particular furnace here described, to about $30), the apparatus is cheap, as well as simple and effective.

In practice, we have enclosed the furnace in a larger mass of powered lime, to reduce the loss of heat by radiation.

The magnesia blocks required, and also the crucible, were made for me by Muller & Cie., of Ivry Port, near Paris.

I am indebted to Mr. H. P. Tiemann, a student in my laboratory when this furnace was introduced, for determining, by calculation and cautious experiments in detail, the current needed for the temperatures desired, and thus assisting me to avoid the fusion or injury of the platinum wire which might have resulted from tentative use not thus guided.

The Zinc- and Lead-Deposits of North Arkansas.

BY JOHN C. BRANNER, STANFORD UNIVERSITY, CAL.

(Mexican Meeting, November, 1901.)

No precise geographic limits can be given for the zinc- and lead-region of North Arkansas. In general terms it lies N. of the Boston mountains and W. of the St. Louis, Iron Mountain and Southern railway; but the prospecting and the development of the ore-deposits have not gone far enough to outline more than vaguely the areas over which workable deposits are to be expected. The tardiness of the development of the region is due in part to its topography, as a hilly and partly mountainous country, through which there have been no railways until recently. There is no longer any doubt, however, about the existence in that region of large bodies of zinc-ores.

I. General Geology.

The general geology of the region is, in the main, quite simple, but that of the ore-deposits is less so.

The zinc-regions of North Arkansas lie about the southern flanks of the Ozark dome. The rocks are approximately horizontal, but have a gentle southward dip away from the axis of this dome. Figs. 1, 2 and 3 show the broad features of the topography and geologic structure.

South of the zinc-region, the sandstones and shales of the lower Coal-Measures form the north-facing escarpment of the Boston mountains. Beneath the Coal-Measure rocks are the limestones and cherts of the Lower Carboniferous; and these rest upon Silurian and Ordovician beds.

The uppermost beds (Coal-Measures) have been cut into by erosion along the mountain-slopes so that their edges or outcrops have a meandering or dendritic form. The same thing happens with the Lower Carboniferous beds; but these, having been more or less protected by the overlying Coal-Measures, have broader bases, and cover a much larger area. In places,

the beds of the Coal-Measures have been removed until the Lower Carboniferous rocks, as a thin covering to the Silurian beds, extend many miles N. of the margin of the overlying strata.

Inasmuch as all the beds are nearly horizontal, the meandering streams have cut their way down through them all, and we not infrequently have the Ordovician rocks exposed in the bottoms of the valleys, the Lower Carboniferous upon the slopes, and the Coal-Measures capping the hills. A type of this geology is shown in Fig. 4. Throughout much of the region, however, the Coal-Measures have been completely removed, and we have now only the Lower Carboniferous cherts and limestones in the hilltops, and the Ordovician beds in and along the valleys. Over a large part of the region all the Carboniferous rocks have been removed, and there remain only the Ordovician beds.

In addition to these general features of the region, the rocks are more or less folded and faulted; and inasmuch as the ores have been affected by the folds and faults, these features of the geology are of especial importance, and are entitled to much more attention than they have received from mining companies.

II. Ore-Deposits.

The ores seem to occur only in the Ordovician and Lower Carboniferous rocks, but I know of no reason why they should not occur in the Coal-Measures also, except that these later rocks have been removed from most of the region, and that, according to the theory of the origin of the ores, a greater difference of level or a greater depression of the beds of the Coal-Measures would be required to bring the ores into these higher rocks.

The ores may be genetically classed as (1) bedded deposits, mostly contemporaneous with the rocks in which they occur; (2) vein-deposits, of later age than the enclosing rocks, and occurring (*a*) along faults or fractures, or (*b*) filling brecciated beds, formed along underground water-courses; and (3) alteration-products, chiefly carbonate- and silicate-ores, derived by alteration from the sulphide-ores of the first and second divisions.

1. *The Bedded Deposits.*

Some of the zinc-ores occur disseminated through beds of chert or dolomite. In these cases the ore is confined strictly to certain beds, while the strata above and below contain, or may contain, no zinc, at least so far as can be seen with the naked eye—small gash-veins, which occasionally cross both the ore-bearing and the barren beds, being excepted. The zinc is usually pretty evenly disseminated through these ore-bearing beds (Figs. 5, 6, 7 and 8), but it often happens that the beds are richer in one place and poorer in another; and sometimes the ore, instead of being disseminated, occurs in streaks or gashes through the ore-bearing bed. (Figs. 9, 10, 11 and 12.) One of the most interesting things in connection with the bedded deposits is that, in several instances, the beds are found to be richer in the troughs of the synclines than elsewhere.

Instances might be given to show that the ore-beds may be sometimes traced for miles along an outcrop, richer here and poorer there, but always the same bed. These bedded deposits are regarded in the main as the originals from which all the other zinc-deposits of North Arkansas have been, either directly or indirectly, derived.

Just how these zinc-bearing beds originated seems to be fairly plain, so far as most of the cherts and dolomites are concerned. The rocks are all of Ordovician age and organic origin. That they were laid down in the sea is clearly indicated by the corals and other marine animal fossils found in them. The only apparently tenable theory as to the source of the ore is that it was derived from the land of the period during which the beds were deposited. I conceive of the zinc and lead as carried down in solution from the land into the sea, and precipitated, in the form of sulphides, in the sediments covering the sea-bottom, through the agency of the organic matter of the chert and dolomite beds, which furnished the sulphur. That all the sedimentary beds do not contain these zinc- and lead-ores is probably due to the fact that the purely mechanical sediments, such as sands and clays, did not contain the organic matter necessary to remove these minerals from solution.

It is not supposed, however, that the sphalerite crystals were originally as large as those which we now find. They were probably even microscopic at first, but some became enlarged at

Fig. 1.

A Bird's-eye View of North Arkansas, Looking Eastward. (From Branner's relief map of Arkansas.)

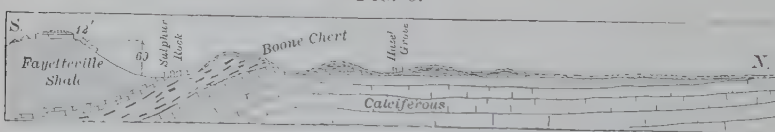
the expense of their neighbors; the latter passing into solution and recrystallizing upon the larger ones, in the manner pointed out recently by Ostwald.* I have been disposed to think that these crystals were formed before the cherts were consolidated, and it still seems to me probable that such was the order of events in some instances.† I am aware, however, that some of the rocks have been altered in places to granular quartzites, probably from cherts. At least the rocks in some instances are

FIG. 2.

A Generalized N.–S. Section Across the Ozark Plateau and the Boston Mountains.

made up partly of quartz crystals arranged along parallel bands, and among these crystals are scattered here and there crystals of sphalerite. In such a case it seems as though the materials of the original rock had been altered in place without obliterating or obscuring the original bedding-planes, but admitting, at the same time, of a slight shifting of the rock-constituents. This kind of rock is shown in Figs. 13, 14 and 15. Dr. Lindgren tells me that he thinks it is possible for

FIG. 3.



A N.E.–S.W. Section through Sulphur Rock and Hazel Grove, Showing the General Geology of the Eastern End of the Zinc-Region.

sphalerite to replace part of a rock and to crystallize in its usual form, even in the midst of solid quartz.

In any event, the ore-bearing beds have been buried under

* *Uber die Vermeintliche Isomerie des Rothen u. Gelben Quecksilberoxyds u. die Oberflächenspannung Fester Körper.* W. Ostwald, *Zeitschr. f. Phys. Chemie.*, Aug., 1900, xxxiv., 495–503.

† An interesting occurrence of both galena and sphalerite in soft sedimentary rocks is mentioned by Harris and Veatch in their late (1899?) report on *The Geology of Louisiana*, pp. 225–226.

sediments of later Ordovician age, of Silurian and possibly Devonian age, and, still later, of the Lower Carboniferous and the Coal-Measures. All these strata from the Ordovician to the Lower Coal-Measures are approximately conformable with each other. There is therefore no great break in the series if we except the Devonian interval, which is marked at places by a pockety bed of phosphate-rock. Since the region was lifted from beneath the sea these bedded deposits have been cut into by stream-erosion, so that the ore-beds are now, in some cases, exposed along the sides of the valleys, and are found to penetrate the residuary hills.

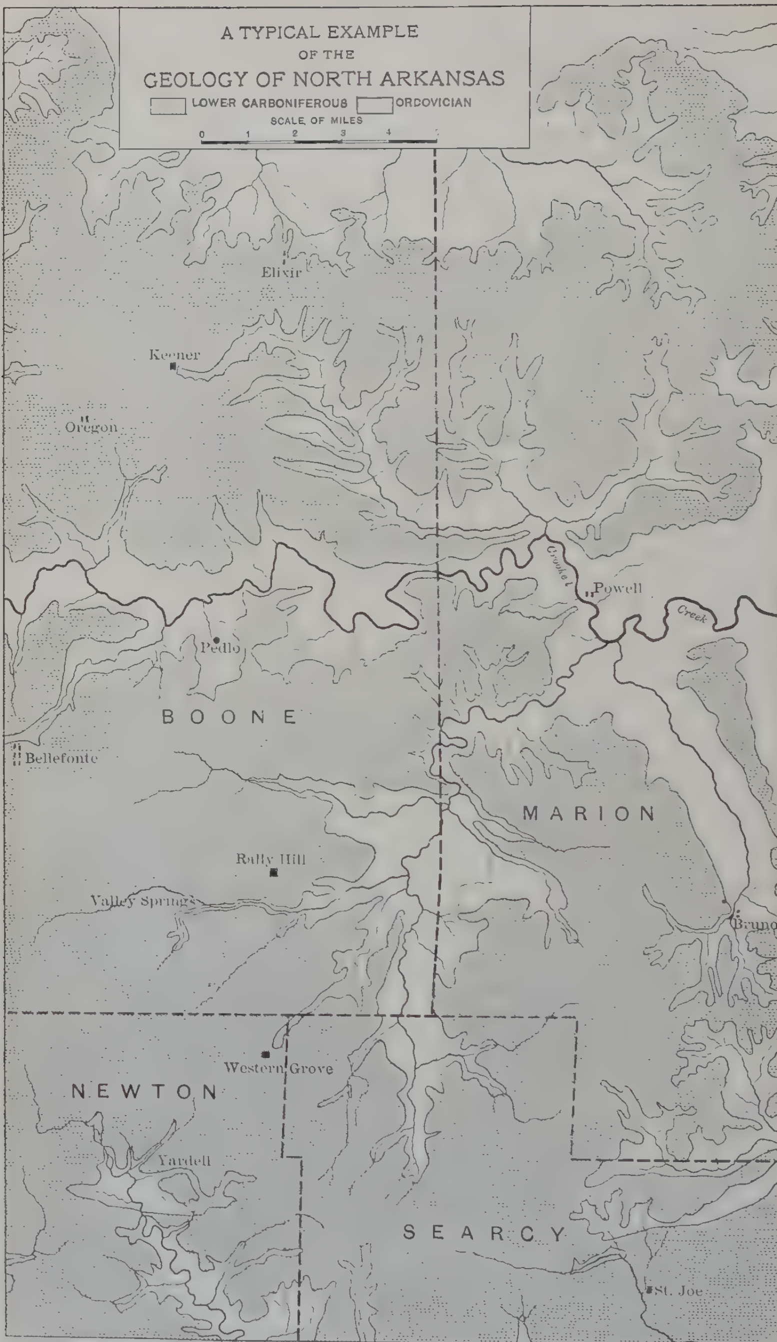
2. *Vein-Deposits.*

By vein-deposits are here meant ore-bodies which have accumulated in fractures, however made, and are of later age than the beds in which they occur. These fracture-deposits belong to two large classes:—first, those formed in faults and allied fractures; second, those formed along old subterranean waterways other than faults.

a. Fault-Deposits.—The faults in the zinc-region of North Arkansas have broken across the whole series of rocks there represented, from the Ordovician to and including the Lower Carboniferous. I have no doubt that these faults pass up into the rocks of the Coal-Measures also; but I have not had occasion to trace any of them from the zinc-region into and across the area of Coal-Measures. Some of them are normal, others are reversed, and still others show no vertical but only a lateral displacement; several of them seem to be double reversed faults. In some instances they can be traced for many miles, in others they are purely local. In some cases the fractured zone along a fault is several hundred feet wide; in others, the walls are closely pressed together. (Fig. 16.) Occasionally a fault is marked by a ledge of siliceous breccia; in other instances there is no topographic evidence of the fault.

At several places the fractured zones contain either zinc- or lead-ores or both, and at one place the fault contains copper-ore. The breccias along the lines of fracture are frequently cemented with dolomite spar and sphalerite. Geologically, these ore-bearing breccias may lie either below, opposite, or

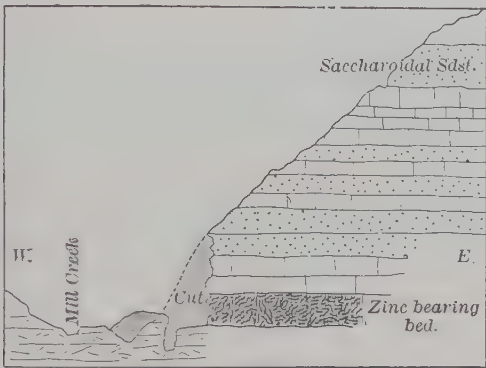
Fig. 4.



A Typical Example of the Geology of the Zinc-Region of North Arkansas.

above the bedded zinc-ores. Sometimes the faults have cut both Ordovician and Lower Carboniferous rocks, in which case the ores are found in juxtaposition with Lower Carboniferous

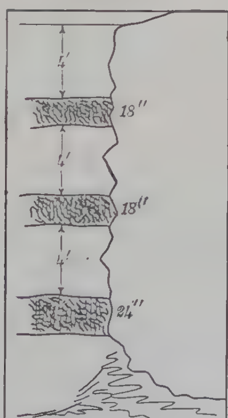
FIG. 5.



Section at the Marble City Mine on Mill Creek near Wilcockson.

cherts and limestones, but they probably extend downward to the Ordovician. The ore-deposits in the vicinity of Boxley, in Newton county, belong to this type.

FIG. 6.

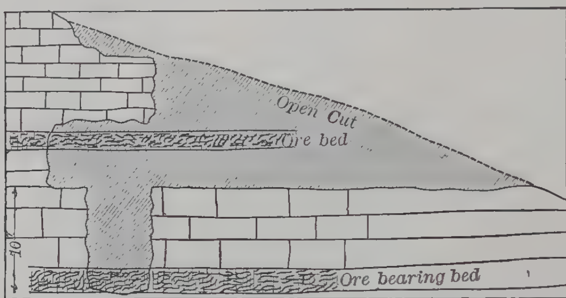


Section in a Tunnel of the McIntosh Mine, Showing the Zinc-bearing Beds (shaded).

The ores are found both in the brecciated zone along the faults and in the minor fractures that accompany the faults. In some instances the ore is more abundant at one side of the

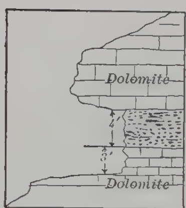
fault than in the fault itself. In many instances, perhaps in all of them, where there is ore in the breccia of a fault there is

FIG. 7.



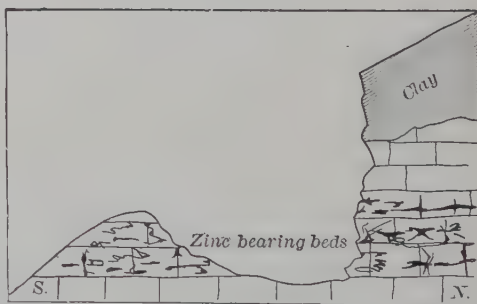
Section at the Little Rock Mine, Showing the Bedded Ores.

FIG. 8.



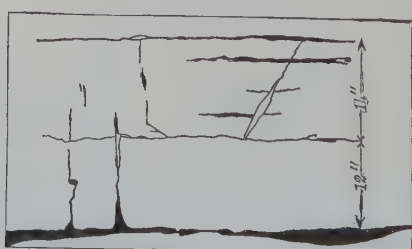
Section at the Face of an Open Cut at the Lion Hill Mines, Showing Zinc-Ore Disseminated through a Chert Bed.

FIG. 9.



Section at a Baxter County Mine, Showing the Streaks of Zinc-Ore in a Single Bed.

FIG. 10.



Section in a Mine, Showing a Case of the Deposition of Zincblende along Bedding-Planes and in Veins Crossing the Beds.

a little ore in the walls of the faulted zone, but as a rule this ore does not penetrate far into them.

b. Waterway-Deposits.—The second class of ore-bodies newer than the surrounding rocks is that formed along ancient underground waterways other than faults. These deposits are quite

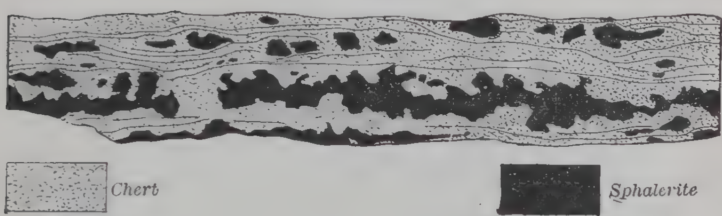
FIG. 11.

A Case of the Pockety Distribution of Sphalerite through Chert.

FIG. 12.

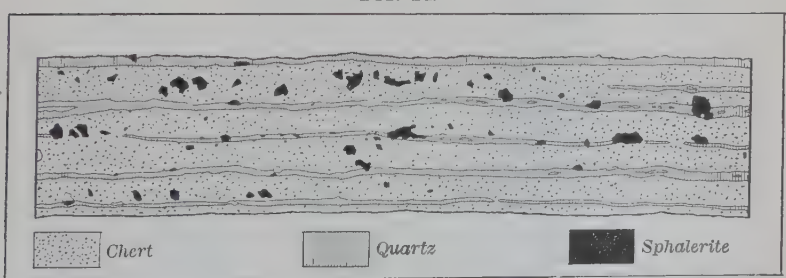
Plan of the Face of a Drift Showing the Zincblende in Crevices and along Bedding-Planes.

FIG. 13.



"Layer-Cake" Ore from the Little Rock Mine on Hall Mountain. (Natural size.)

FIG. 14.



Altered Siliceous Rock with Sphalerite and Quartz. (Two-thirds natural size.)

irregular in form and direction, and may be either large or small, rich or poor. It sometimes happens that these old waterways have followed certain structural features, such as syn-

clinal folds, guided apparently by the impervious character of adjacent beds and by the porous or open nature of the conduct-

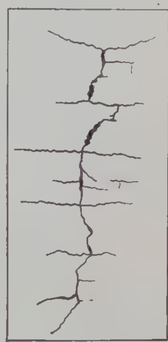
Fig. 15.

Bedded Disseminated Zincblende in Chert, Red Cloud Mines. (Natural size.)

ing beds. In other cases they have cut across the strata, changing their directions frequently, and abruptly going up, down or sidewise without any apparent cause. These water-

ways appear in some instances to have been more or less open caves. In the course of their history the walls have crumbled and the cavities have been closed, partly by the breaking down of roofs and sides and partly by the deposition, along with the fragmental material, of dolomite spar and of more or less sphalerite, and sometimes of secondary chert. In many cases these old water-courses have been completely choked up and abandoned; in others, some water is still flowing through them. The rocks of which the breccia is made are of all the kinds found in the immediate vicinity. There are frequently in this breccia fragments of the original chert or dolomite, containing the disseminated ore. (Fig. 17.) Occasionally there are brecciated masses of amorphous silica that resembles ordinary potter's clay, and disintegrate like a fuller's earth when placed in water. The accompanying cut shows some of this amorphous silica containing zinc-ore. (Fig. 18.) An analysis was made of this peculiar gangue with the following results:

FIG. 16.



Form of Ore-Streaks along a Closely Pressed Fault, Panther Creek Mine. (Height of face, about 8 ft.)

Analysis of a Gangue of Amorphous Silica from the Climax Tunnel.

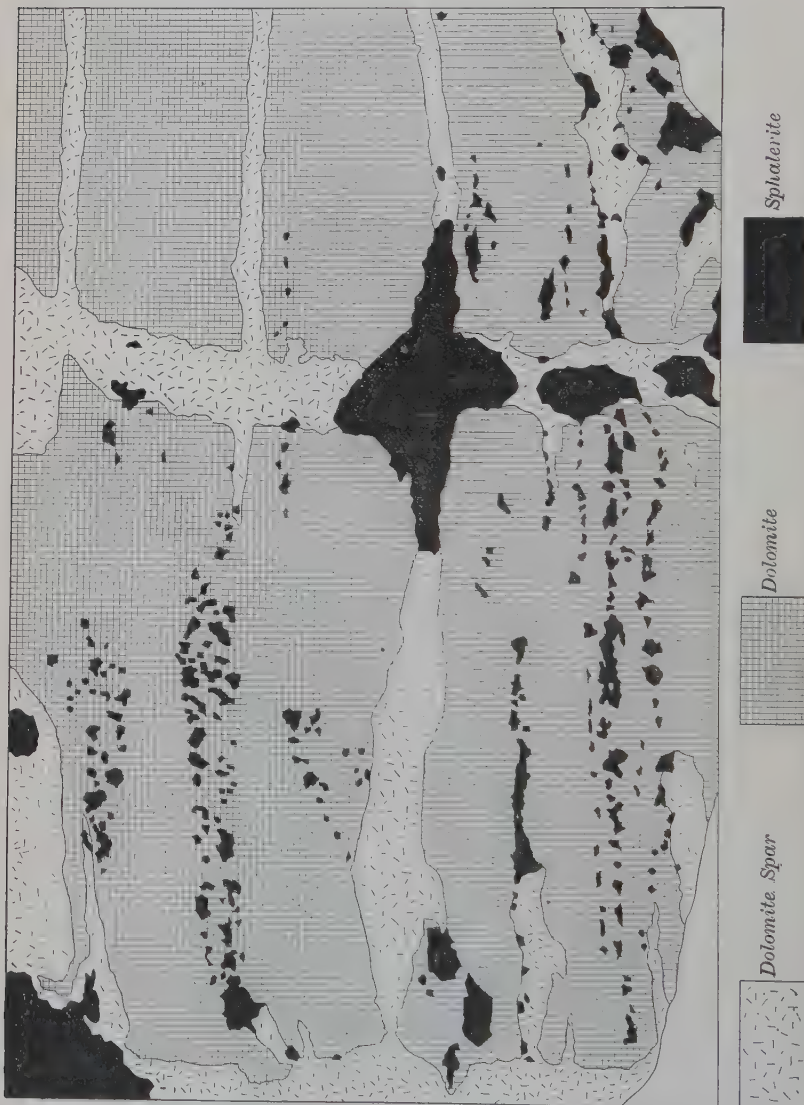
	Per cent.
Silica, SiO_2,	83.51
Iron and Alumina, Fe_2O_3, Al_2O_3,	11.37
Magnesia, MgO,	trace.
Lime, CaO,	0.51
Sulphide of zinc, ZnS,	0.61
Phosphoric acid, P_2O_5,	0.26
Manganese, MnO,	trace.
Loss on ignition, H_2O,	2.79
	99.05
Hygroscopic water,	1.39

It is to be expected that the ore-bodies formed along faults and those formed along other water-ways should occasionally merge into each other. Such a deposit is exposed at the Lost mine in Baxter county. (Fig. 19.)

The bedded deposits are, as a rule, easily distinguished from

the vein-deposits, not only in the beds themselves but often in large hand-specimens; but deposits formed along the faults are not to be distinguished from those formed along the old water-

Fig. 17.



Dolomite with Zinc-blende Disseminated and in Veins of Later Age, Georgetown Mine. (Natural size.)

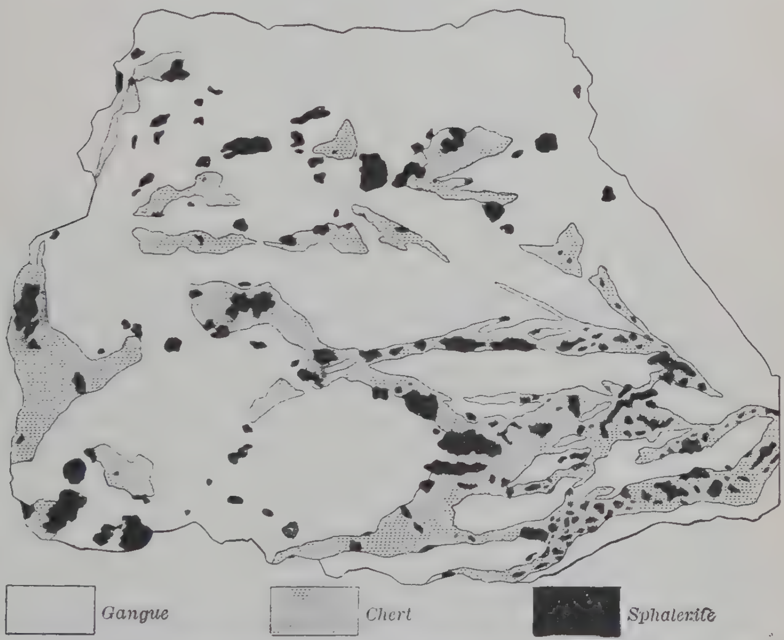
ways, except where something can be seen of the form and structural relations of the ore-bodies themselves.

Origin of the Fissure-Ores.—Inasmuch as the bedded ores are apparently original to the beds in which they occur, we do not

need to go further than these bedded deposits in search of a source for the fracture-deposits and other water-way-deposits of North Arkansas. In some instances the ore-deposits along fault-zones are below, and in others they are above, the bedded ores—the word "above" being taken in either its geologic or its hypsometric sense, or in both senses.

It must be remembered that the region under consideration has been folded somewhat, and has been profoundly affected by faulting; there have also been great changes of level. In

FIG. 18.



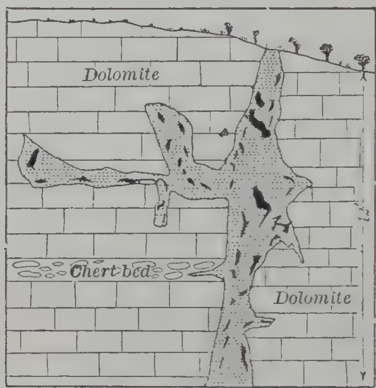
Brecciated Zinc-Ore in a Gangue of Chert and Amorphous Silica, from the Climax Mine. (Natural size.)

addition to these internal alterations, denudation has changed the surface-features of the entire region, cutting down through the rocks and modifying both the surface and the subterranean drainage.

It does not seem extravagant to suppose that in the process of these many and great changes the meteoric waters, in their passage through the rocks, should have dissolved the zinc at one place and deposited it in another. In some cases the underground waters might naturally be expected to come in

contact with the bedded zinc-deposits, and to reach the surface by way of faults that penetrate both Ordovician and Lower Carboniferous beds. And it is not improbable that, in spite of their having been deposited at lower levels, subsequent crustal

FIG. 19.

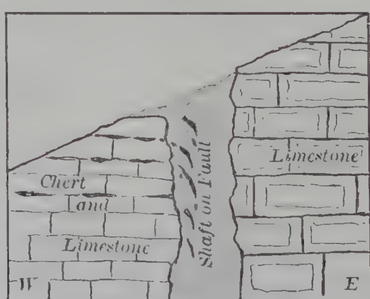


Lead-bearing Vein upon and adjacent to a Fault, Lost Mine, Baxter county.

changes might leave the new deposits higher, both geologically and hypsometrically, than the beds from which the ores were derived.

Such I conceive to be the explanation of the lead- and zinc-ores found along faults in contact with and slightly penetrating

FIG. 20.

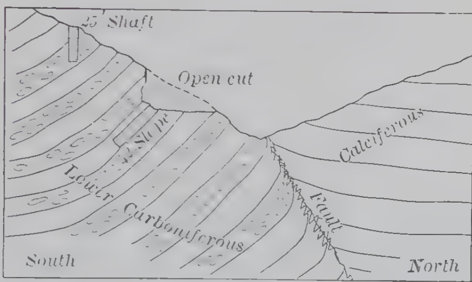


Section at the Baker and McGrath Shaft, Big Buffalo Region.

the walls of Lower Carboniferous rocks in the Big Buffalo region near Boxley, in Newton county. (Fig. 20.) At the Panther creek mines, near Jasper, the ores are found in Lower Carboniferous cherts and limestones along and adjacent to a fault.

At the Big Hurricane mines on Hurricane creek, a tributary of Davis creek, Newton county, the zinc is found in the Boone chert (Lower Carboniferous); but this zinc-bearing chert is within a few feet of a great fault, in which Ordovician rocks are brought up against the Lower Carboniferous beds. (Fig. 21.)

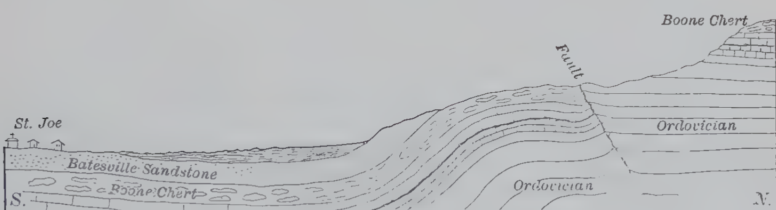
FIG. 21.



Section at the Big Hurricane Mines.
The zinc-ore is in Carboniferous rocks near a fault.

The Tomahawk copper-mines are on a fault in which the Lower Carboniferous rocks are let down against the Silurian and Ordovician beds. At the St. Joe mines the ores are found along a fault on which the Ordovician and Silurian rocks are in contact with Lower Carboniferous cherts and limestones. (Fig. 22.)

FIG. 22.



Section Showing the General Geology near the St. Joe Fault.

At a few places on Tarkiln creek the Boone chert (Lower Carboniferous) contains some zincblende and calamine, but the exposures in the vicinity of these prospects are not sufficient to enable one to make out the details of the geology. It is quite possible that these ores occur near a fault: if there is no fault near at hand, however, this occurrence of zinc-ore in the Lower Carboniferous cherts is unique for North Arkansas, so far as I have seen the geology.

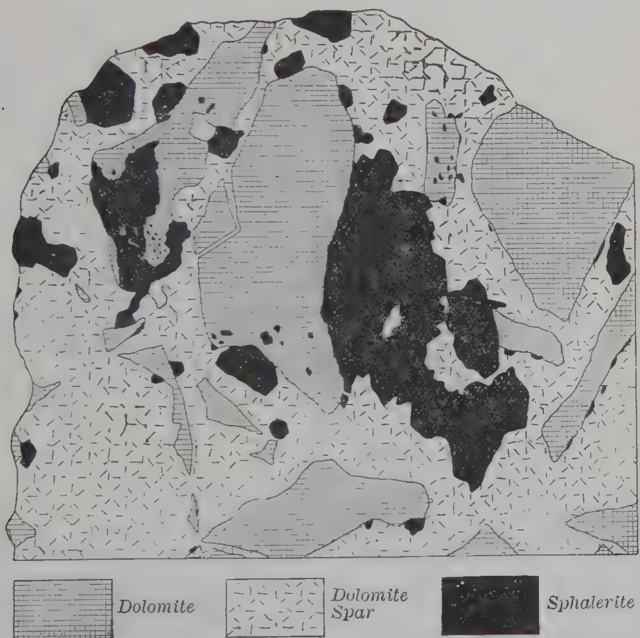
Fig. 23.

Brecciated Siliceous Dolomite at the Creek Dig, Maryhattiana.

The evidence goes to show that we may have ores deposited in the faults in contact with Lower Carboniferous rocks, in contact with Ordovician and Silurian rocks, and in contact with both Ordovician and Lower Carboniferous rocks. But in all these cases there seems to be no reason to appeal for an origin for these ores to any other source than the bedded deposits of the Ordovician.

Origin of the Waterway-Deposits.—The deposits formed along old waterways other than faults or fractures, so far as they have

FIG. 24.



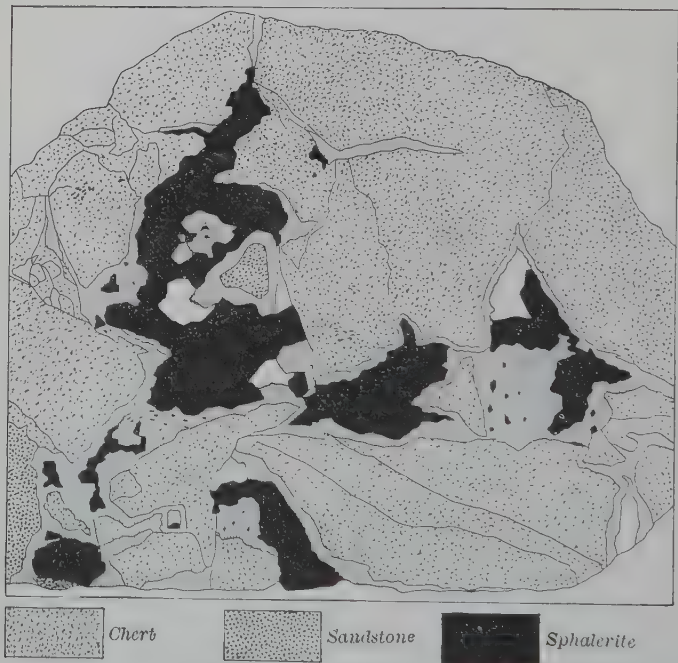
Breccia from the Democrat Mine, Showing the Usual Form—Angular Fragments of Dolomite Cemented by Dolomite Spar and Sphalerite. (Natural size.)

been uncovered by the miners, are confined to the Ordovician rocks; but it does not seem improbable that there may be similar deposits in the limestones of any age found in the zinc-region.

The explanation of these waterway-deposits seems to be that the meteoric waters penetrating the earth have dissolved the limestones and dolomites and, in some cases, have formed subterranean streams. These stream-channels have been made up of a series of caverns of various sizes connected with each

other, very much as are the openings along any existing water-course. These old channels are now crushed in, filled with angular fragments of the wall-rocks cemented by calcite, dolomite spar, secondary chert, and, in some instances, with sphalerite and with galena. The breccias thus formed must represent a considerably larger space than was occupied by the original waterways. Such would be the natural result of the shattering of the walls of a cavity. (Fig. 23.)

FIG. 25.



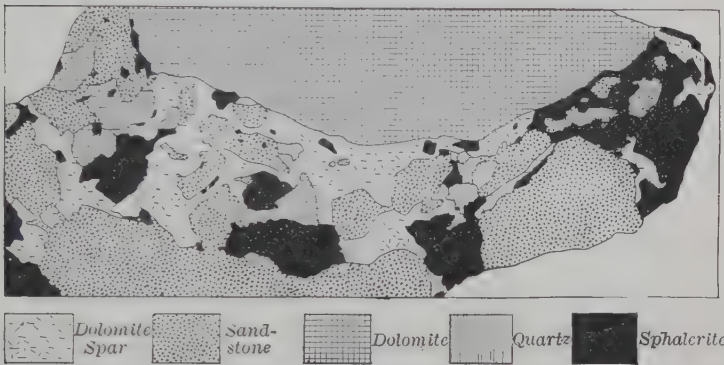
Brecciated Chert and Sandstone Cemented with Quartz and Sphalerite. White Eagle Mine. (Natural size.)

Occasionally one may find the breccias forming a bed for a short distance, ending abruptly against solid and undisturbed beds, and having unbroken beds below and beds but little disturbed above them. Such cases appear to be the exposed edges of cavernous breccias. The cavernous breccias are generally dolomites; but they sometimes have mingled with them bits of chert and sandstone, apparently brought by the ancient streams from adjacent beds of chert and sandstone. (Figs. 24, 25 and 26.) These breccias may be either ore-bearing or bar-

ren, rich or poor; but the miners of the region are aware of the fact that, wherever breccia is found, ore should be looked for.

In addition to these large ore-bodies, small gash-veins and ore-stringers are found in connection with the bedded ores, and

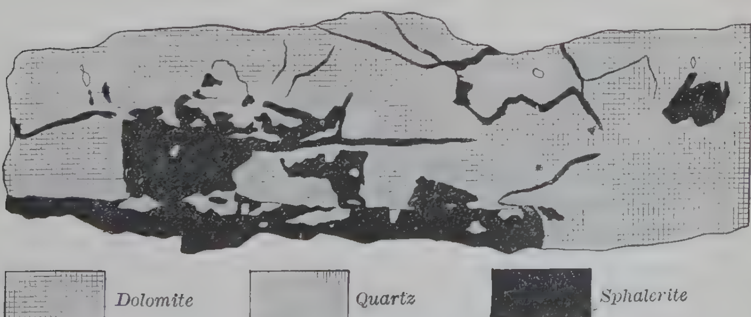
FIG. 26.



Breccia of Dolomite and Sandstone Cemented with Dolomite Spar, Quartz and Sphalerite. Red Cloud Mine. (One-half the natural size.)

also with the veins and brecciated deposits. They are of but little economic importance, except when they occur in or adjacent to the beds of disseminated ore or convenient to the other and larger ore-bodies. These small veinlets appear to have

FIG. 27.



Cavities in Dolomite Filled with Quartz and Sphalerite. (Natural size.)

originated by the deposition of the ore in fractures, however produced. Some of these cavities appear to have been caused by shrinkage (Fig. 27), perhaps due to the dolomitization of the beds in which they occur; others seem to have been

formed by the dissolving out of the rock along joints and bedding-planes. (Fig. 28.)

3. *Alteration-Products.*

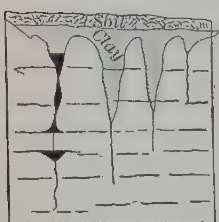
The alteration-products of the region offer nothing new or unusual. They consist chiefly of smithsonite and calamine, but the so-called "tallow-clay," described below, is worthy of mention in this connection. Where lead-ores prevail, there is usually more or less anglesite, cerussite and pyromorphite.

III. The Relations of the Geologic Structure to the Ore-Bodies.

1. *The Bedded Ores.*

It has already been pointed out that the ore-bodies of Arkansas are partly contemporaneous with, and partly newer than, the rocks with which they are associated. The bedded ore-deposits were laid down in horizontal sheets along with the cherts, quartzites and dolomites, through which they are now disseminated. Whatever changes have affected these rocks have affected the ores which are a part of them. Where the beds are bent, the ore-bodies are bent; where the rock-beds are faulted, the ore-bodies are similarly faulted; and where streams have cut down, through the rocks, valleys of various depths and widths, these valleys have been cut through the ore-beds likewise. The miners and prospectors of North Arkansas often have a fear of blasting into the face of one of these bedded zinc-deposits, lest it "go blind," or pinch out, a little further in. The bedded ores of North Arkansas do vary more or less in the thickness of the ore-bearing portion of the bed and in the percentage of sphalerite in a given amount of gangue. But the bedded deposits are remarkably even in thickness and richness; and if they change for the worse in a short distance, they may be depended upon to recover their richness within an equally short distance. No *sudden* changes in the thickness or richness of the bedded ore-

Fig. 28.



Part of the West Wall of the Canady Mine, Showing Sphalerite in Joints and Bedding-Planes.

bodies should excite alarm: it is only the *gradual* thinning out or impoverishment of the beds that should cause uneasiness. Of course a fault may, and often does, bring the ore-beds up against a barren wall; but beyond the fault the bed can usually be re-located without much difficulty and followed further.

But while the rock-beds and the bedded ore-deposits have retained the same general relations to each other, there have been going on since the beginning slight alterations which have ultimately had an important effect upon both rocks and ores. These alterations have been produced by the action of waters, aided by whatever acids and alkalies they may have found at hand from time to time. The surface-waters penetrating the soils and rocks have obeyed the laws of hydrostatics, and have followed whatever channels these laws and the nature of the rocks permitted. Their movements have not been rapid, but, for the most part, very slow. In their passage through the rocks these waters have dissolved certain minerals, and shortly afterwards deposited them again. Reference is not here made to surface-phenomena, such as we have in the formation of smithsonite, calamine and stalactitic deposits, but rather to the solution and re-deposition of such minerals as sphalerite, and even of quartz and chert.

It is not uncommon to find in the region under discussion the rocks associated with the Ordovician zinc-beds to have undergone changes which have turned thin-bedded cherts or some other siliceous sediments into rocks made up of double layers of small quartz crystals, so arranged that the upper layers have the crystals terminating downward, while the lower ones have their crystals pointing upward. In several instances of the kind there are crystals of sphalerite mingled with the quartz. Examples of the kind are especially abundant at the openings on the Little Rock claim on the N. side of Hall mountain, near Yellville, and in certain parts of the Morning Star mines on Rush creek. At many places cavities in the rocks are now in process of being filled with crystals of zinc-blende, calcite, dolomite, and, in some cases, with crystals of quartz.

It is a fact, then, that sphalerite passes into solution, and that it re-crystallizes. From the fact that we have cavities filled with crystals of sphalerite that must have been deposited since

the formation of the fractures, it is also evident that the zinc passes (in solution) from one part of the rocks to another. And inasmuch as the waters passing through the rocks afford a vehicle for carrying this and other mineral constituents, we must attribute such removal and re-deposition to these waters.

We may here inquire what the ultimate effect of such action upon the original ore-beds would be. It must lead to local loss and gain—to local diffusion and concentration—to local impoverishment and enrichment of the ore-bearing rocks. The ores are moved very slowly through the rocks along the channels followed by the waters, and there must be an accumulation or enrichment where the chemical and physical conditions are most favorable.

A word is in place in regard to what is here meant by subterranean watercourses. It is not intended to refer in this place to what are usually understood by underground streams,—large bodies of water, which issue as springs or flow through caves,—but rather to the courses followed by what is more commonly known as seepage-water. This movement of water goes on not only in the higher levels, but also at depths considerably below sea-level. There is an idea prevalent in geology that surface-waters are prevented from penetrating the crust of the earth below the level of the sea, and that there is no active solution and removal of rock-constituents below sea-level. This seems impossible or, at least, improbable. If we suppose an open tube with one end on land and the other submerged in the sea, water poured in the upper or land end would flow out beneath the sea. If the channel is through the rocks instead of through a metal pipe, the water will flow seaward in the same fashion. Professor Shaler tells of a subterranean spring off the coast of Florida whose channel on the land must lie below sea-level.* Such springs are known also in other parts of the world. It should be remembered, also, that the process of concentration—either the one here suggested or some other—has been in operation in the zinc region of North Arkansas for a very long time. The original deposits were laid down in the ocean during the Ordovician or Lower Silurian period; and from the time the beds rose a lit-

* *Bulletin of the Geological Society of America*, 1895, vi., 155.

tle above the level at which they were deposited down to the present—we know not how many millions of years—the waters have been passing through these rocks.

In such a process of reasoning we must be on our guard against certain inferences that may appear at first glance to be warranted. It is not to be inferred, for example, that the present subterranean watercourses have been in existence from the beginning. On the contrary, the evidence is conclusive that old waterways have been choked up and abandoned and new ones have been established. For example, we have now exposed at many places on the surface on the sides of hills, and in the residual soils, stalactitic deposits that must have been formed inside of caverns. Many of the brecciated deposits that were formerly loose, open masses, through which the water could readily move, are now closely cemented by the deposition in their cavities of sphalerite, calcite or dolomite spar. Miners are familiar with the fact that pipes used to drain mines are often more or less choked and eventually closed by the deposition in them of mineral matter. If the water were flowing through a heap of broken stones the result must be the same—the spaces between the stones along the waterway would be closed up and the fragments cemented into a breccia.

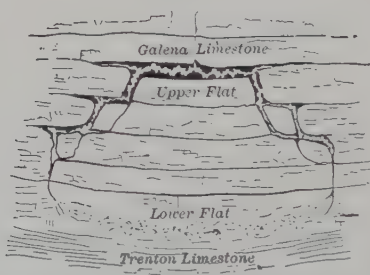
The Wisconsin Region.—Much confidence is felt in the conclusions here stated as to the nature and method of formation of the ore-bodies under consideration; and, while the author would hesitate to apply the theory to other regions not examined by him, he has ventured to inquire whether it might not be applicable to the Wisconsin zinc- and lead-region. The conditions shown in the accompanying illustration (Fig. 29), reproduced from Chamberlin's report on the zinc- and lead-region of Wisconsin,* seem to find a ready explanation in the theory here offered for the Arkansas deposits. This particular section looks as though the lower flat ore-body had been formed along an old waterway, the channel of which had been closed partly by the falling of the roof and partly by the deposition of mineral matter. Many of the examples of the peculiar features of the zinc- and lead-deposits of Wisconsin given by

* "The Ore-Deposits of Southwestern Wisconsin." By T. C. Chamberlin, *Geol. of Wis.*, vol. iv., pp. 451–479.

Chamberlin seem to be satisfactorily explained by the theory of ore-formation here presented.

Why Some Ore-Beds are Unaltered.—After such a long period of chemical activity within the rocks, why is it that there yet remain any of the original beds of zinc-ore? Why have not all been made over into secondary deposits? There seem to be two possible explanations of the undisturbed condition of these original disseminated ores. First, the underground waters have not passed through all the rocks alike. Some places have been more, and others less, affected by that agency; and if for any reason the underground water did not pass through the rocks of a given area, those rocks and their minerals would remain unaffected. In the second place, certain of the bedded ores are in a chert so thoroughly compact and im-

FIG. 29.



The "Flats" and "Pitches" of the Wisconsin Zinc- and Lead-Regions. (After Chamberlin.)

penetrable that this physical character and condition of the gangue-rock seems to offer at least a partial explanation of the unaltered condition of the ores.

Relations of Synclines to the Ores.—If the hypothetical history here assigned to the North Arkansas zinc-ores is thus far correct, we are forced to conclude that the geologic structure of the region is of the utmost importance in the determination of the present distribution of the ores.

In an elevated region of approximately horizontal or very gently folded sediments, the waters falling upon the ground and soaking into the earth tend to seek the bottoms of the synclinal troughs. The process of ore-accumulation in such a region would tend, therefore, to carry the ores into the synclines. The rocks of the zinc-region, although not far from

horizontal, are gently folded. Wherever folds have been exposed in the zinc-mines, the bottoms and sides of these folds have been found richer in zinc than the adjacent portions of the same beds. To this rule I know but few exceptions. The inference seems to be warranted that the synclinal troughs should be located and examined for the richer zinc-accumulations. (Figs. 30, 31 and 32.)

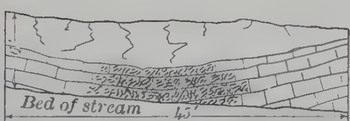
Subterranean waters do not, of course, always follow synclines. Sometimes they emerge from the crests of anticlines, and at

Fig. 30.

Ore-Face at the Lion Hill Mines. Richest at the bottom of a gentle syncline.

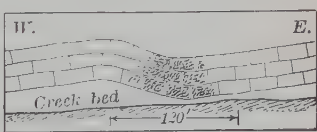
other times they appear to disregard structural features altogether. Ores left by waters moving through, and deposited in, these apparently irregular and uncertain channels would have equally irregular and uncertain distribution.

Fig. 31.



Zinc-Ore in the Bottom of a Syncline at the Virginia J. Mine. (Purdue.)

Fig. 32.



Zinc-Ore in a Syncline at the Roberts Mine. (Purdue.)

2. *The Influence of Faults.*

The idea that faults, fractures and breaks of one kind or another are the best places in which to seek ores, has had much influence with the prospectors of North Arkansas. Experience has justified, also, their notion that wherever there is a break in the beds, however small, zinc is likely to be found, though it does not always occur there. If such fractures do contain ores, it is because they have afforded convenient paths for underground waters. But it is true, and was to have been expected,

of waterways along fractures, just as it is true of those originating otherwise, that they are not all rich in ores, and some of them contain no ores whatever.

An interesting feature in connection with the faults is, that the ores have sometimes accumulated, not in the faults themselves, but close to them on one side or the other. This is probably due to the fact that when faults are formed by pressing together the beds on two sides of a fracture, this pressure sometimes bends the beds near the fault so as to open them along the bedding-planes.

When the ores occur along the ancient underground water-courses guided by folds, faults or fractures, they can be located, approximately, at least, by a study at the surface of the geological structure. The brecciated deposits (except those upon faults) are not so easily located from surface-structure; they require prospecting by a system of bore-holes or shafts, or by the careful following of the brecciated masses from any exposure uncovered.

In regard to the faults and folds, it may be well to repeat here the reminder that neither fault nor folds are necessarily straight lines. We should be on our guard against the theory that the ores of North Arkansas, however they may have originated, follow certain fixed directions. No doubt they do, in certain cases, follow definite lines, and these lines are sometimes straight, but it must not be inferred that such lines are to be prolonged indefinitely, or that the strike of an ore-body on one property is necessarily the course to be expected of an ore-body in another place. Where the ores have accumulated in fractures, the fractures are seldom straight for a long distance, and other fractures in the vicinity are quite as liable to have an altogether different bearing. Where the ores have accumulated along synclinal folds or other structural features, the same law holds good: the direction of these structural lines is liable to change at any point, and whether and where they do change, can only be determined by an examination of the geology.

3. *Analogies in Tennessee Deposits.*

In connection with the general subject of zinc-deposits, the writer may observe that during the years of his field-work upon

the Arkansas zinc-region he made several trips to the zinc-deposits of East Tennessee. The Tennessee zinc-ores are in rocks of the same geologic age and precisely like the zinc-bearing beds of North Arkansas; but instead of being approximately horizontal, the Tennessee beds are much folded and faulted. The ores, however, are found in breccias very similar to those of Arkansas; and the deposits in some instances follow, and are richer, along the synclinal folds. Much of the zinc-mining in Tennessee has been done upon the carbonate ores, the alteration-products from the sulphides.

IV. Composition and Quality of the Ores.

Sphalerite.—The excellent character of the sphalerite of North Arkansas is worthy of note. The accompanying analyses show the composition of specimens of clean zincblende, taken at random. Attention is directed to the low iron- and high zinc-contents. Out of a large number of analyses of sphalerite, the largest amount of iron (Fe_2O_3) found was 0.67 per cent.

Analyses of Sphalerite from North Arkansas Showing Iron Contents.

Mines.	Zinc, Zn.	Sulphur, S.	Silica, SiO_2.	Iron, Fe_2O_3.	Magnesia, MgO.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Yankee Boy	65.88	31.77	0.10	0.62	0.14
Hiawatha	66.27	32.53	0.21	0.39	trace
Governor Eagle	64.48	32.16	1.88	0.26	0.00
Panther Creek	65.88	32.30	0.00	0.49	trace
Prince Frederick	65.68	33.33	0.09	0.15	0.03
Hunt, Malloy and Blevins	58.68	20.36	0.10	0.20	0.10+
St. Joe	65.73	32.92	0.11	0.15	0.08
Bear Hill	66.46	32.30	0.25	0.15	0.20+

Smithsonite.—Analyses of the smithsonite show it to be of excellent quality. Those given below, however, having been made from hand-specimens for the purpose of ascertaining the composition of certain types, must not be accepted as representative of car-load lots. Owing to the large amount of foreign material held mechanically in all large lumps of smithsonite, analyses of car-load lots would necessarily run lower in zinc than do these particular specimens.

Analyses of Smithsonite.

	Morning Star Mine. Per cent.	Legal Tender Mine. Per cent.
Zinc oxide, ZnO,	64.31	62.20
Carbon dioxide, CO_2,	34.93	33.86
Water, H_2O,	0.58	2.30
Silica, SiO_2,	0.10	0.02
Magnesia, MgO,	0.03	0.18
Lime, CaO,	0.90	1.25
Iron, Alumina, Fe_2O_3, Al_2O_3,	0.12	0.21
Cadmium, Cd,	trace	trace

The zinc oxide in the analysis of the specimen from the Morning Star mine is equivalent to 51.60 per cent. of metallic zinc; that of the specimen from the Legal Tender is equivalent to 49.91 per cent.

Turkey-Fat.—The yellow mineral popularly known in the mines as "turkey-fat" is smithsonite, colored with a little cadmium oxide. This kind of smithsonite occurs at several of the mines, but is most abundant, perhaps, at the Morning Star, on Rush creek. The composition of a typical example is shown by the following analyses:

Analyses of "Turkey-Fat," a Yellow Variety of Smithsonite.

	Per cent.	Per cent.
Zinc oxide, ZnO,	63.84	61.20
Carbon dioxide, CO_2,	34.60	
Water, H_2O,	1.09	
Silica, SiO_2,	0.25	
Magnesia, MgO,	0.07	
Lime, CaO,	0.70	
Cadmium oxide, CdO,	0.90	0.82
Iron, Fe_2O_3, and Alumina, Al_2O_3,	0.42	trace

Fig. 33 shows how this form of smithsonite is frequently found partly filling crevices in the more or less altered chert.

Smithsonite sometimes occurs as a red, yellow, or brown "sand." In such cases the so-called sand-grains are small individual crystals of smithsonite. Sometimes these particles are loosely held together, sometimes compactly cemented.

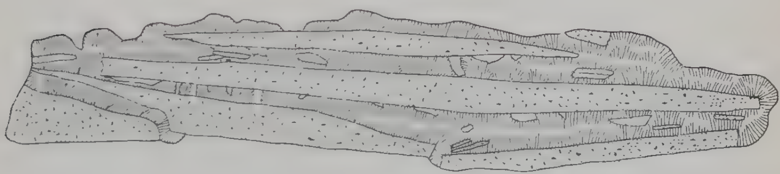
The early zinc-mines of Arkansas were mines of smithsonite, and the ore was found in the surface-clays and soils, along and near the outcrops of deposits of zinc-blende. Although there

is hardly a zinc-prospect in North Arkansas which has not yielded some smithsonite, there is but little search nowadays for smithsonite alone. I feel reasonably confident, however, that when the search for the zinc-ores of North Arkansas has been properly systematized, large bodies of zinc carbonate will be discovered. These are most likely to be in regions of deep rock-decay.

Calamine.—Calamine is much less abundant in Arkansas than either sphalerite or smithsonite. The most abundant deposits now known are in the Sugar Orchard district. The Almy mine is at present the most remarkable producer of calamine in the State.

There are other prospects in the vicinity of Sugar Orchard creek which, upon further development, will likewise yield large quantities of calamine.

FIG. 33.



Yellow Smithsonite Deposited in Crevices in Chert. Morning Star Mine. (Natural size.)

On account of lack of time and funds, no quantitative analyses have been made of the Arkansas calamine.

Tallow-Clay.—What is commonly known in the zinc-mines as "tallow-clay" or "buck-fat" is not a definite mineral, but a mixture, probably of common clay and the mineral calamine. At present this material is not looked upon as an ore of zinc, simply because no satisfactory process of smelting it has been devised.

Tallow-clay has a peculiar "feel," by which it is commonly recognized. It may be either red, yellow or brown in color. It occurs, in pockets and seams in the rocks, in nearly all of the zinc-mines of North Arkansas. In some of the mines it is found in great abundance. The following analyses show the composition of typical Arkansas tallow-clays:

Analyses of Arkansas Tallow-Clays.

	Buffalo Mine.	Big Elephant Mine.	Post Boy Mine.	Coon Hollow Mine.	Kansas Mine.	Markle Mine.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica, SiO_2	51.03	45.10	40.91	37.04	41.67	36.65
Alumina, Al_2O_3	16.98	16.52	9.33	8.85	8.47	10.05
Zinc oxide, ZnO	14.10	13.97	34.79	37.76	35.88	37.54
Ferric oxide, Fe_2O_3	5.98	5.65	2.25	1.68	2.35	2.86
Ferrous oxide, FeO	0.69	3.16	0.52	0.42	0.33	0.53
Lime, CaO	1.16	2.70	3.42	3.58	1.36	2.20
Magnesia, MgO	1.34	1.58	0.48	0.77	0.51	1.62
Potash, K_2O	0.44	1.15	......	0.27	0.57	0.35
Soda, Na_2O	0.00	0.62	0.42	0.56	0.07	0.40
Water, H_2O	8.88	10.89	9.02	8.76	8.28	8.92

Several other forms of zinc—hydrozincite, zincite, aurichalcite and goslarite—are found in the zinc-regions, but they occur too sparingly to have any importance as ores of zinc. Besides these, there are probably still other zinc-minerals here, which have not as yet been identified.

V. General Conclusions.

The following general conclusions seem to be warranted:

1. The zinc-ores of North Arkansas are remarkably pure.

2. The zinc-ores were originally deposited as disseminated ores in sedimentary beds, mostly of organic origin, in which some of them are still found.

3. The position of the ores in the beds has been changed, more or less, since they were originally deposited.

4. These changes have been going on ever since the original deposition, and are still in progress.

5. By means of such changes, vertical and other fissures have been filled with ores brought into them by circulating waters from above, from below, and from the sides.

6. The position of the ores in the secondary deposits has been determined largely by those structural features that have guided the underground waters in their passage through the rocks.

7. The accumulations of ores have taken place sometimes along synclinal troughs, sometimes in fissures along fault-lines, and sometimes in the breccias formed along other ancient underground watercourses.

8. In many instances the subterranean waterways have been closed by the deposition of mineral matter, and the water has sought other channels.

9. The carbonates and silicates have been produced, mostly in place, by the alteration of sulphide-ores.

Diverse Origins and Diverse Times of Formation of the Lead- and Zinc-Deposits of the Mississippi Valley.

BY CHARLES R. KEYES, DES MOINES, IOWA.

(Mexican Meeting, November, 1901.)

DURING the past decade the genesis of the lead- and zinc-deposits of the Mississippi valley has received special attention from many distinguished observers. But their united efforts, instead of settling all disputed questions, have, in many respects, involved the general problem in greater uncertainty than would be thought possible under the circumstances. In place of the harmony of opinion that might be expected, there is unexpected disagreement, largely due to the fact that, instead of giving attention to a possible multiplicity of ore-producing conditions among the different deposits, the attempt has been made to bring all deposits under a single genetic head.

To a new observer of the lead- and zinc-deposits of the Mississippi valley, it appears at the outset that all the deposits cannot possibly have had the same genesis. In fact, different modes of origin have been often asserted for the ore-bodies, but the difficulty has been that each writer has referred them either all to one category or all to another, and no intermediate ground has been considered possible. Such a position now appears to be clearly untenable.

The opinion that, in the deposits of the region under consideration, the ore-materials represent original depositions, made at the time the rocks themselves were formed, is no longer held by any authority, and therefore need not be considered here.

Of late years, a number of writers have attempted to account for the presence of the lead- and zinc-ores on the hypothesis that the metallic materials arose in heated solutions from the

non-sedimentary zone of the earth's crust, through openings formed by profound faults. Posepny* and Jenney† especially have emphasized this view.

On the other hand, other students of the lead- and zinc-deposits of the same region do not consider as possible, for any of these ore-bodies, a deep-seated source.

The problem involved has not been generally recognized as yet by students of ore-deposition; but, among investigators of rock-metamorphism, it has been repeatedly solved in many different phases. Briefly stated, the petrographical principle referred to is, that the same kind of minerals may have in the same limited area, and even in the same rock-mass, a diverse genesis. The revelations of the microscope along this line in connection with the crystalline rocks also bear directly upon the phenomenon of ore-deposition. They argue for a varied origin of the metalliferous minerals. Many of the massive crystalline rocks which were once thought to be always secondary, have been conclusively shown to be sometimes primary, in character. As a noteworthy example the common rock-forming minerals, allanite and epidote, have been lately described.

Allanite, the iron-silicate of the rare earths, cerium, lanthanum, yttrium, didymium, and erbium, long considered one of the infrequent rock-forming minerals, has been found‡ to be very widely distributed, often as an important accessory. Owing to the fact that this mineral cannot withstand without change of physical character a temperature higher than a dull-red heat, it was adduced as decisive evidence against the igneous origin of the rocks in which it occurred. Scheerer,§ in advocating an aqueo-igneous theory of the origin of granite, suggested that, on account of the presence of water, the magma might cool down considerably below the temperature necessary for solidification under the conditions of ordinary dry fusion, and thus allow minerals which cannot endure a high degree of heat to crystallize out before other constituents less fusible by the simple dry method.

Since Scheerer's time, the presence of allanite in igneous rocks has been noted by numerous observers, many of whom

* *Trans.*, xxiii. (1894), 303.

† *Id.*, xxii. (1894), 215.

‡ *Am. Jour. Sci.* (3), vol. xxx. (1885), p. 108.

§ Poggendorff's *Annalen d. Phys. u. Chemie*, Bd. lvi. (1842), p. 479.

are mentioned in a recent review of the subject by the writer.*

In this connection, the lime-silicate of iron and aluminum, epidote, is even more instructive. Until recently it has always been regarded as a secondary ingredient in eruptive rocks. It is now believed to originate in igneous rocks in four distinct ways. It is regarded as an original constituent of certain granites of Maryland, where it also occurs in parallel intergrowths with allanite.† Epidotes, regarded as primary in character, have been noted by Lacroix‡ in certain rocks from Finistère, France, and by Brögger§ in pegmatites from Arendal, Norway. As a result of fumarole-action, epidote often develops abundantly along the contacts of eruptive rock and beds containing lime. The mineral is widely distributed through rocks dynamically metamorphosed. Even in the weathering of igneous rocks, epidote is frequently one of the most abundant resulting products.

In some Maryland granites, epidotes of at least three different origins are believed to occur in the same rock-mass. The four methods of genesis mentioned above do not include the common process by which ores are most widely formed, that is, directly through the agency of circulatory waters.

Allanite and epidote are representatives of a large number of metalliferous and non-metalliferous substances which enter into the constitution of igneous rocks. They indicate how widely metal-bearing components may occur, and how differently they may be found without being of extraneous origin. They have been selected as examples for the reason that they occur as primary minerals under conditions far more extraordinary and seemingly impossible than those under which many metallic salts are found.

The lead- and zinc-deposits of the Ozark region present at least four distinct types of genesis. They have been formed through: (1) fumarole-impregnation, or pneumatolysis; (2) fissure-occupation, in which heated waters rise from the depths; (3) precipitative action, or reduction in contact with organic

---

* *U. S. Geol. Sur.*, 15*th Ann. Rept.* (1895), p. 704.

† *Bull. Geol. Soc. America*, vol. iv. (1893), p. 305.

‡ *Bull. Soc. Min. de France*, t. xii. (1889), p. 139.

§ *Zeitsch. f. Kryst.*, xvi. Bd. (1890), p. 95.

matter; or (4) crevice-accretion, in joint-spaces and porous layers, and derived from ordinary groundwaters.

1. *Fumarole-Impregnation.*—This type is found in the Algonkin granites at Silver Mines, 20 miles east of Ironton, Missouri, and at a number of other localities in the neighborhood. The petrographical characters of the vein-materials and country-rock at the Silver Mines have been lately investigated by Haworth.* The wall-rock is the common coarse-grained red granite of the region, composed chiefly of orthoclase and quartz, with some biotite, microcline and plagioclase. The veins, from 3 to 5 ft. wide, dip about 50° S. The country-rock for 10 to 12 ft. on each side of the vein shows marked metamorphism. The altered belts on each side are now almost typical greisen, or a mixture of quartz and mica, the feldspars having been completely changed. Both in the vein-stuff and in the altered walls a number of interesting minerals have been developed, among which may be mentioned zinnwaldite, topaz, fluorite, wolframite, muscovite and sericite.

The veins themselves are composed largely of quartz, carrying silver-bearing galena and the sulphides of iron and copper. Picked samples of the ore are said on good authority to have yielded as high as 300 oz. of silver to the ton; while the average of 50 assays was about 46 oz. to the ton. As Haworth remarks, the nature of the alteration of the granite walls of the fissures, taken in connection with the presence of the various peculiar minerals already mentioned, leaves no doubt that there was genuine fumarole-action, during the operation of which vapors from below not only corroded the wall-rocks, but also brought up in volatile form different elements necessary for the production of the several minerals.

The time of formation of this and similar veins of the district is pre-Cambrian, since the filled fissures are all truncated by pre-Cambrian erosion, leaving the Cambrian strata unbroken over all.

2. *Fissure-Occupation.*—Somewhat allied in manner of formation to the class of deposits described are the argentiferous lead- and zinc-ores of central Arkansas, on the southern border of the Ozark highland. Comstock† seems to associate these

* *Missouri Geol. Sur.*, vol. viii. (1895), p. 83.

† *Arkansas Geol. Sur.*, Ann. Rept., 1888, vol. i., p. 219.

silver-bearing ores with a peculiar system of faults which traverse the folded region diagonally. The évidence which he produces indicates almost conclusively that the ore-bodies were formed by thermal waters rising along dislocation-planes. Other observers confirm this view. Some of the ore-bodies appear to occur in the vicinity of old hot springs, similar to those which are still in operation in this region.

The conditions thus presented in the central Arkansas region, which are so much like those prevailing in many parts of the Rocky mountains, appear to have afforded Jenney the chief grounds for applying the general principle to all the deposits of the Mississippi valley. But all later investigation clearly demonstrates that the so-called faults of SW. Missouri are for the most part very different structures from those of the central Arkansas district.

3. *Precipitative Action.*—Of great theoretic interest, but of small practical import, are certain occurrences of ores which have been precipitated by the contact of metalliferous solutions with organic matter. The blende reported by Wheeler* as found in lignite from the middle Carboniferous sandstones, near St. Louis, deserves special mention in this connection. Of still greater significance are the blende-deposits occurring in the coal-beds of Morgan county, Missouri,† in amounts sufficient to enable occasional shipments to be made. Of like significance are the pyrite tubules in the loess-deposits.‡

The principle is perhaps of more importance than has been generally thought. And the reducing effect of the coal, natural oil and gas may have aided greatly in the formation of the ore-bodies of SW. Missouri. It is known that in a broad belt of territory, 150 miles in length and extending along the western border of the State, the rocks are impregnated to a notable degree with rock-oils.

4. *Crevice-Accretion.*—The gash-veins and crevices of SW. Missouri and of the Dubuque district, and the disseminated ore-bodies of SE. Missouri, all appear to have the same origin. The most recently acquired information in all these districts precludes the supposition that the ores were formed from

* *Trans. St. Louis Acad. Sci.*, vol. vii., 1895, p. 123.

† *Trans.*, xxx. (1901), 346.

‡ *Am. Jour. Sci.* (4), vol. vi. (1898), p. 299.

thermal waters rising from the deep-seated zones. All evidence points to their deposition from circulatory underground waters at ordinary temperatures under well-known hydrostatic conditions, but probably in presence of some organic matter. The only essential difference between the disseminated ores and the crevice-ores is, that in the case of the former, the deposition took place chiefly in horizontal porous layers, and in the latter chiefly in the vertical spaces opened out along joint-planes or small faults in rocks having no porous layers.

The great significance attached to the faulting in the Ozark ore-regions, as permitting access to the deep-seated zones, loses much of its force when the character of the displacements is taken into consideration. Most of the so-called faults are of small throw; and, so far as observation goes, few appear to extend beyond single terranes. The faulting is largely merely the minute but very frequent crustal adjustment which is everywhere going on throughout the region. It occurs within the ore-mining districts to no greater extent than outside in the Coal-Measures.*

In the SW. Missouri district the conditions are peculiar. This area appears to be rising much more rapidly than the waters can degrade the country. As a result, much of the water that falls upon the surface is carried off in deep underground channels. In the case of the larger streams, the roofs are continually caving in, and the disentombed waters flow in deep, narrow canyons. The faulted and shattered aspect of the rocks, so apparent everywhere throughout the district, is due mainly to this cause, and not so much to profound dislocation, as is commonly believed.

Southwest Missouri is a land of springs,† which gush out to form streams of considerable size. The subterranean water-courses are subject to the same laws of aggradation as the rivers open to the sky. Barriers arise which cause the cavernous courses to silt up, as it were, often to the extent of hundreds of feet. The local groundwater-level for the time rises accordingly. Within a range of several hundreds of feet there may thus be no discernible relationship between the groundwater-level and the character of the ore.

---

* *Bull. Geol. Soc. Am.*, vol. v. (1894), pp. 231 to 242.

† *Missouri Geol. Sur.*, vol. xii. (1898), p. 33.

The faults of this region must be subjected to rigid inquiry before generalizations can be based upon their presence as to their influence upon the genesis of the ores. Many of the frequent faults of small throw have been manifestly produced since the ore-bodies were formed. This is especially true in SE. Missouri. Moreover, the few known great faults are not usually associated with ore-bodies. The Cap-au-Grès fault,* N. of St. Louis, which may be regarded as the basal boundary of the Ozark dome towards the NE., and which has a throw of probably 1000 ft., presents no evidence of important neighboring ore-bodies. The great fault of the Mine la Motte district†—a vertical dislocation of several hundred feet—appears to have no ore-bodies along its course, though the most important mines of the region are only a short distance away. The Mine la Motte mining company has expended already thousands of dollars in exploring this fault for ore-bodies, but without success. The same may be said of certain dislocations in northern Arkansas.

Posepny‡ calls attention to the oblique impregnation-planes in the dolomite at Mine la Motte, a phenomenon which he is inclined to ascribe to a former groundwater-level. "But," he says, "it was, and is, inconceivable to me how these cavities could be filled with sulphides." The explanation presents no serious difficulties on a hypothesis different from that which he advocated.

The evidence seems conclusive, that, in formulating a hypothesis for the formation of the lead- and zinc-ores of the Mississippi valley, a single simple agency cannot be regarded as giving rise to all the ore-deposits. Any theory accounting for the presence of these ore-bodies must take into consideration a number of very different geological processes, geological conditions and geological structures.

The geological date of the formation of the ore-deposits has been a theme of more or less extended discussion; but there has been little in the way of exact data on the subject. Since the periods of ore-formation are dependent somewhat upon the orogenic movements (these movements being the main factors initiating new conditions favorable to local concentrations of

* *Proc. Iowa Acad. Sci.*, vol. v. (1898), p. 58.

† *Missouri Geol. Sur.*, vol. ix. (1895), pt. iv., p. 61.

‡ *Trans.*, xxiii. (1894), 303.

metallic substances), the cycles of physiographic development have a practical bearing upon ore-genesis. In physiography, geologists have come into possession of an exceedingly delicate test for determining earth-movements. In the region occupied by the Ozark highland this test has been proved to have exceptional value in fixing the time-relations of the ore-deposits.

There appears to be only one possible opinion as to the age of the argentiferous galena veins in the granites of SE. Missouri. They were clearly formed in pre-Cambrian times. They nowhere penetrate the overlying stratified rocks. The upper surface of the crystallines is everywhere an eroded surface—recent, of course, wherever now exposed to the sky; pre-Cambrian, where still covered by the indurated sediments. The veins are composed usually of basic rock-material, often of white quartz chiefly, but sometimes of metalliferous substances and various exotic minerals.

In the case of the veins at the Silver Mines, more than 1000 ft. of the upper part have been removed since Tertiary times. In Cretaceous and in pre-Cambrian times the amount removed was probably much greater. At all events, both granite and vein-stuff are now perfectly fresh, showing that the present surface-level is a considerable distance below the original surface when the veins were formed.

Regarding the ores occurring in the sedimentaries, Posepny* makes the following singular statement:

"The deposits occurring near the 'islands' of granite and porphyry have special interest. While the Silurian limestones of the surrounding country, farther from these islands, present chiefly only lead- and zinc-ores, other metals, such as copper, cobalt and nickel, occur as the Archæan foundation rocks are approached; and this circumstance is, to my mind, an indication that the source of the lead deposits also is to be sought in depth."

As shown conclusively elsewhere, the crystallines of the region had everywhere solidified, and had been subjected to profound erosion long prior to the formation of the sediments containing the ore-deposits to which he thus refers.

As to the deposits belonging to the second category—those of the central Arkansas region—the time occupied in forma-

* *Trans.*, xxiii. (1894), 303.

tion of the separate ore-bodies has probably been brief; but, taken as a whole, the process of ore-formation has doubtless extended more or less continuously from the Cretaceous to very recent times, possibly to the present day.

No accurate date can be assigned to the limited deposits of the third class. They may have been formed at any time between the end of the middle Carboniferous and the present. The probabilities and the evidence favor a comparatively recent date for their deposition.

To the fourth group, which contains practically all of the productive deposits at present worked extensively, a very recent geological date is assigned. In the Ozarks, deposition certainly began to proceed vigorously with the last period of uplifting of the region, which occurred since Tertiary times. The uprising is even now evidently going on rapidly, and, with it, ore-formation also. The formation of blende crystals, a quarter of an inch in size, on old nails immersed in mine-waters for 15 years, gives an idea of the rapidity with which the process may actually go on. It is not at all unlikely that most, if not all, of the Ozark deposits of this class were really formed within the memory of man.

Notes on the Pigholugan and Pigtao Gold-Regions, Island of Mindanao, Philippine Islands.

BY J. CLAYTON NICHOLS, M.E., GRAND JUNCTION, COLO.

(Mexican Meeting, November, 1901.)

I. The Pigholugan Region.

The principal mines of this region are 7 miles SE. from Gusa, and about 4 miles in a direct line from the seacoast. Gusa is a small town on the north coast of Mindanao, 4 miles east from Cagayan, the capital of the province of Misamis.

The mines are reached by steep, narrow trails over ridges varying in altitude from 1100 to 1600 feet above sea-level.

The whole region is covered with a thick growth of tall grass, except a few spots on the sides of some of the hills, where there are patches of timber and jungle.

The formation is slate and serpentine, except the tops of the highest peaks, which are capped with volcanic rocks with bunches of coral on top of them.

The two principal mines are the Abaca-an and the Pigholugan.

The Abaca-an is on the side of a steep hill rising abruptly from the east side of the Kugman river, and at the mouth of a little stream. The Kugman river at this point has an altitude of 800 ft.; and it drops to sea-level in 4 miles.

The Pigholugan mine is three-fourths of a mile east from the Abaca-an and at from 300 to 500 ft. greater altitude. Both mines are in the same geological horizon and are practically the same geologically. The country-rock is a soft, gray, argillaceous slate, the strata of which strike S. 75° E. and dip 50° S.

Each mine has half a dozen, or more, small veins of quartz, from 1 inch to 4 inches wide, running parallel, from a few feet to 50 feet apart, striking N. 30° E. or almost at right-angles with the strata, and dipping 80° E.

Small seams or stringers of quartz, seldom more than an inch wide, cross the veins almost at right-angles. These seams have the same strike as the strata, yet, being almost or quite vertical, cut the strata at an angle of about 50° from the horizontal. There are other narrow seams of quartz in some of the cleavage-planes of the strata and lying conformably with them. The intersections of these three different systems of veins, or seams of quartz, seem to be the places sought as valuable by the native miners.

Deep trenches, several hundred feet long, have been dug along the main veins, and holes have been sunk at the bottoms of the trenches at the crossings of the vertical seams, which occur with some regularity, from 12 to 15 ft. apart.

Many of the holes at the crossings are more than 20 ft. deep; and some of them are not more than 20 in. square. There are two or three more than 50 ft. deep, but none deeper than 75 ft.

Some of the workings are very old: a tree 8 in. in diameter is growing from the wall of one of the shafts. The rock, while not hard, is tough, and stands remarkably well.

The character of this formation is familiar to the "pocket-miners" of California, and they would have no difficulty in knowing how to prospect for "pockets" in this district.

Information in regard to the quantity of gold taken from these pockets is very indefinite.

Eight thousand pesos ($4000 gold) are said to have been taken from one hole, and five thousand pesos ($2500 gold) from another.

The owner of one of the mines said he had taken 2000 taels from it in sixteen years, but how many men he worked he did not state. The Spanish Government report gives the production for one year at 600 taels.

The region is several miles in extent, and the titles of only four or five mines have passed from the Spanish Government into private hands, the rest being public domain.

The probability of finding other mines, equal in richness to those that have been worked, and are now owned by individuals, is very great. Such mines would not be suitable for large corporations, but ought to be worked under the supervision of the owner, or a trusted agent, as the values would come in small and very rich bunches.

II. The Pigtao Region.

This gold region embraces the territory drained by the Iponan river and its tributaries.

This territory is divided by the miners into two mining districts, the dividing-line being drawn E. and W. through the town of Taglimao, on the Iponan river, about 15 miles from where it flows into the sea. All the territory N. of this town, or down the river, is known as the Lower, and S., or up the river, as the Upper, Pigtao mining-district.

From San Simon to the sea, a distance of 10 miles, the river flows tortuously through a beautiful and very fertile valley, from half a mile to a mile and a half wide. Above San Simon, the valley narrows to a gulch or cañon, with steep or precipitous hills on either side, rising to a plateau from 300 to 500 ft. above the river. This plateau is cut by numerous gulches and side-streams almost to the level of the river.

The main mining-region is above the mouth of Pigtao creek, the confluence of which, with the Iponan river, is about 22 miles from the sea. Above this point, on both sides of the Iponan river, every small stream or gulch has been thoroughly worked as a placer, and the points of all the ridges next to the

river, between these gulches, have been mined to some extent.

The beds of some of the larger streams have been worked to bedrock in places only; and it is quite evident that the bedrock of the river itself has never been touched at all, except in places along the rim. In one locality an effort was made to work out a hole in the bed of the river, just above the mouth of Pigtao creek. A new channel was dug across the neck of a bend, a dam was built and the river was turned, but before bedrock had been reached in the old channel the dam broke, the works were submerged and the enterprise was abandoned. The natives still mine in the side-streams by digging holes as deep as they can reach under water, scooping the gravel up with cocoanut shells, and then washing it in *bateas*.

Unquestionably there is gold in some quantity on the bedrock of the Iponan river above the mouth of Pigtao creek, but how much, or how far it is to bedrock, can only be determined by expensive prospecting. It is my opinion that bedrock is seldom less than 12 ft. and never more than 40 ft. below the surface of the water.

Except where parts of the conglomerate ledges have broken off and rolled in the river, there are no boulders larger than a man's head. The gravel-bars from bank to bank will average about 200 ft. in width. Bedrock is a soft sandstone, the strata of which lie almost horizontal in some places, and in others dip as much as 10° from the horizontal. On top of the sandstone strata on the benches are some strata of soft, yellowish porphyry, streaked and mottled with red hematite. This, when disintegrated, makes a very sticky clay. It is in this soft porphyry or clay that all the bench-mines are located. Judging from the old workings, the values run in streaks, and the porphyry containing the largest quantity of red hematite seems to be the richest. It is very difficult to separate the gold from this material. The natives accomplish it by vigorous rubbing with the hands under water.

While there are some extensive pits on the benches, not a hundredth part of the available ground has been worked. No data of the average value of the dirt or the amount of gold produced per day per man in any of these pits could be procured. They have been worked during the wet seasons; some of them are connected by little ditches with small, wet-weather streams,

while others have reservoirs dug in the soil. In other places the natives carry the dirt to the river during the dry season.

A ridge or range of hills, from 500 to 700 ft. in altitude, extends E. from the mountain range west of Taglimao, and crosses the Iponan river between San Simon and Taglimao. This range is composed of thick strata of conglomerate resting on the soft, light-colored porphyry. The conglomerate strata dip N. and very slightly E. from 10° to 12°. On the tops of the ridges where the conglomerate has been disintegrated, the gravel looks like an old river-bed containing slate, quartz, crystalline and basaltic rocks. The conglomerate is cemented with a volcanic material, and the boulders and gravel become finer as the strata recede from the mountains. The natives mine in the little gulches on the sides of the hills of this range. In some of the larger gulches there are extensive gravel-beds on the sides of the hills, some of which have been worked.

At Capasayanan there is a large pit, where the Monteses have worked. In the dry season they carried the dirt to the Iponan river, half a mile distant. The natives say that a large number of Monteses used to work this mine, but about a hundred died from fever one season, and the mine was abandoned.

In the top-gravel of the bars in the Iponan river, above where these conglomerate strata cross, it is difficult to get a pan of dirt that will show a color, while below, almost to the sea, nearly every pan will show colors. On the upper end of some of the bars, in the short bends of the river, below the conglomerate, pay-dirt for a rocker can be found. From the conglomerate to the sea the gravel is fine, there being no boulders as large as a man's head, and very few larger than a man's double fists. Fully 5 per cent. of the material composing the bars is fine, black sand, of great specific gravity. The gold is also fine; and it is impossible to separate it thoroughly from the black sand without amalgamation.

The bed of the river, calculating the distance between soil banks, will average 300 ft. in width. There are also light gravel-beds, covered with a light burden of soil, outside of the banks. The depth of the gravel to bedrock has not been determined.

The value of the gravel varies considerably, and is governed not only by the currents of the stream but also by its proximity to the side gulches. Where the river flows through the val-

ley, some distance from the hills on either side, the bars contain less gold than where the river flows close to the hills and receives the washings from the gulches.

From where the Cagayan and Opol road crosses the Iponan river up to the large rice-fields, a distance of more than two miles, it is safe to estimate the average value of the gravel at 15 cents gold per cubic yard. From San Simon, up the river 3 or 4 miles toward Taglimao, the gravel will average from 20 to 25 cents gold per cubic yard.

The amount of this gravel that a dredge could handle would be limited more by the capacity of the sluices than by that of the buckets. Such a large percentage of the whole amount of gravel would go through the screens that there would be great danger of crowding the sluices.

These bars are quite accessible for machinery, as ocean-going vessels can anchor near the mouth of the Iponan river, and machinery can be unloaded in scows holding as much as three tons each, which can be taken up the river to the place where the dredge would be set up. In the wet season machinery could be taken in small boats to the upper district.

The great cost of operation would be fuel. The price of coal at this time (February, 1901) cannot be figured on, as extraordinary conditions now exist. When the coal-mines of the Archipelago are opened and operated, coal ought to be laid down at the mouth of the river for 14 pesos ($7 gold), or less, per ton. The cost of taking the coal up the river in small boats would have to be added. In the upper district wood is plentiful, and the cost of fuel would be smaller.

The Iponan river is an ideal stream upon which to work a dredge. At no season of the year is there a scarcity of water, and during a few days only is the water so high as to interfere with operations. The working season is from one year's end to the other. Frost is unknown in Mindanao. The climate is delightful, and the country is healthful and fertile. Parts of it, especially the lower Iponan valley, are thickly inhabited. Native labor is plentiful at a low rate of wages. Tropical fruits, corn, cocoanuts, rice, vegetables and sugar are plentiful and cheap.

Cagayan, which is only 3 miles from the Iponan river, is the capital of the province of Misamis, and has telegraphic communication with the world. It also has a good harbor in which the largest ships can anchor.

Note on Hydraulic Mining in Low-Grade Gravel.

BY WILLIAM H. RADFORD, SAN FRANCISCO, CAL.

(Mexican Meeting, November, 1901.)

HAVING worked some rather low-grade gravel during the past season at a small profit, I give the actual figures, in the hope that other mining engineers interested in this line of work may be thereby induced to do the same, in order that we may all get more data on this little-ventilated subject.

The property here referred to is situated in one of the northern counties of California, where hydraulic mining is still permitted by the courts. The water-right belonging to the mine is a good one, furnishing water during about nine months, whenever there is an average rain-fall, and a fair proportion of the precipitation is in the form of snow. The ditch, about 11 miles in length, is cared for during the rainy months by two men, and during the rest of the year by one; and the water cost last season, delivered at the mine, 0.69 cent per miners' inch. The season commenced in November, 1899, and ended the last of July, 1900. During this time, 655,657 miners' inches (an inch equals 1728 cu. ft. in 24 hours) of water were used for piping, and for sweeping the bed-rock at the end of the season. From actual surveys, this amount of water washed down 1,251,399 cu. yds. of material, consisting of pay-gravel lying on the bed-rock, and varying in thickness from a few inches to 8 ft., and practically barren top-material, consisting of mountain slide, carrying considerable broken rock, clay, and soil. The banks varied in height from 50 to 130 ft., the average height being 63 ft. The grade of the sluices was 7 in. to 12 ft., the boxes being paved with block-riffles 12 in. deep. Long bed-rock cuts extended from the heads of the sluices to within a few feet of the banks, and were kept practically to grade as the work advanced. At first, electric drills were used on this work; but as it was found that heavy blasting shattered the rock too much, and caused slips, these drills were

abandoned, and hand-drilling was substituted. The bed-rock cuts, run in black slate of poor quality, had to be constantly watched, and in places timbered, to prevent accidents. Electric lights were used in the mine during the night-time, and in the tunnel while cleaning-up was going on. Seven clean-ups were made in the sluices during the season, and at the end of the run the bed-rock which had been uncovered was well swept and everything piped down into the bed-rock cuts; these were run down and carefully cleaned and creviced up. The result of the season's work was $31,618.49, showing a value of only 2.52 cents per cu. yd. for the material washed. The bullion obtained came from the following sources:

		Per cent.
Sluices,	$27,315.40	86.39
Bed-rock Ditches,	3,811.23	12.05
Undercurrents (2),	491.86	1.56
	$31,618.49	100.00

The undercurrents were run only three months and a half.

The cost of operation for the season was $27,511.64, which, deducted from the $31,618.49 of bullion produced, left a profit of $4106.85.

The total cost was made up as follows:

		Cost.	Cost per cu. yd.
Care of ditch, reservoir, and siphon: Labor,	$2670.99		
Supplies,	115.55		
		$2786.54	$.00223
Washing (piping),		2401.05	.00192
Drilling in bed-rock cuts: Hand-drilling,	1050.91		
Electric,	269.62		
		1320.53	.00105
Timbering bed-rock cuts,		157.39	.00012
Electric lighting,		598.62	.00047
Sluice-Building and repairing: Labor,	1045.70		
Supplies,	35.50		
		1081.20	.00086
Blacksmithing,		644.02	.00051
Cleaning-up,		968.79	.00077
Moving pipes and "giants,"		898.85	.00071
Breaking rocks and clay,		6124.91	.00490
Clearing ground for piping (cutting brush),		158.37	.00012
General expenses, watching sluices, and odd jobs,		3088.69	.00250
Supplies used in mine,		3015.37	.00241
Taxes, office expenses, legal expenses, surveying, salaries,		4267.31	.00341
		$27,511.64	$0.02198

A résumé of the season's work is as follows:

Period,	9 months.
Water used,	655,657 miner's inches.
Material washed,	1,251,399 cu. yds.
Cubic yards per miners' inch,	1.91.
Area of bed-rock uncovered,	7.314 acres.
Bullion produced,	$31,618.49.
Average yield per inch of water,	4.82 ct.
Average yield per cu. yd. of gravel,	2.52 ct.
Average yield per sq. ft. of bed-rock,	9.8 ct.
Yield per acre,	$4323.00
Average height of bank washed,	63 ft.

The washing of such poor gravel during the past season was due to the fact that the company was finishing up work on one of the benches before moving to another place, and, in doing this, had to wash a large proportion of "rim-gravel," that is, gravel not in the channel, and usually of low grade. Though the profit obtained was small and the final result could hardly be considered a very satisfactory one, still it shows that, under fairly favorable conditions, gravel of quite low grade can be worked at a profit.

The Klein Jig and the Klein Classifier.

BY FERDINAND H. REGEL, ST. LOUIS, MO.

(Mexican Meeting, November, 1901.)

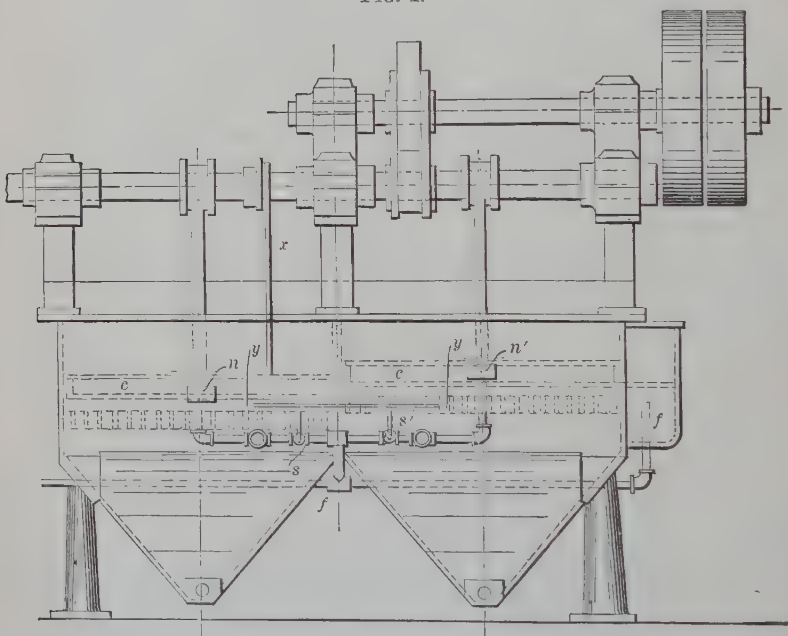
Concentrating-machinery has been wonderfully improved during the past few years both in technical efficiency and in economy of power; and, in the writer's opinion, the prosperity which the mining industry has of late enjoyed is due in large part to this improvement. Many properties are yielding handsome profits at the present time which were considered, a few years ago, too low in grade of ore to be profitably operated; and I think that fully half of these once worthless properties owe their successful development to recent improvements in concentrating-machinery.

The present paper calls attention to a jig and an ore-classifier of new design, invented by Mr. John Klein, and already used in the lead-region of SE. Missouri, and in the Philipsburg dis-

trict of Montana. Having built a number of these machines, and seen them in successful operation, I am able to speak with confidence concerning them.

The general form of the Klein jig, as shown in Figs. 1 and 2, closely resembles that of a Hartz jig, being of the same inverted-pyramid type. It has, however, three main advantages over the Hartz jig of the old style: it requires less power; it has greater capacity; and, above all, it effects a cleaner separation. In a Hartz jig, every plunger is individually operated by an

Fig. 1.



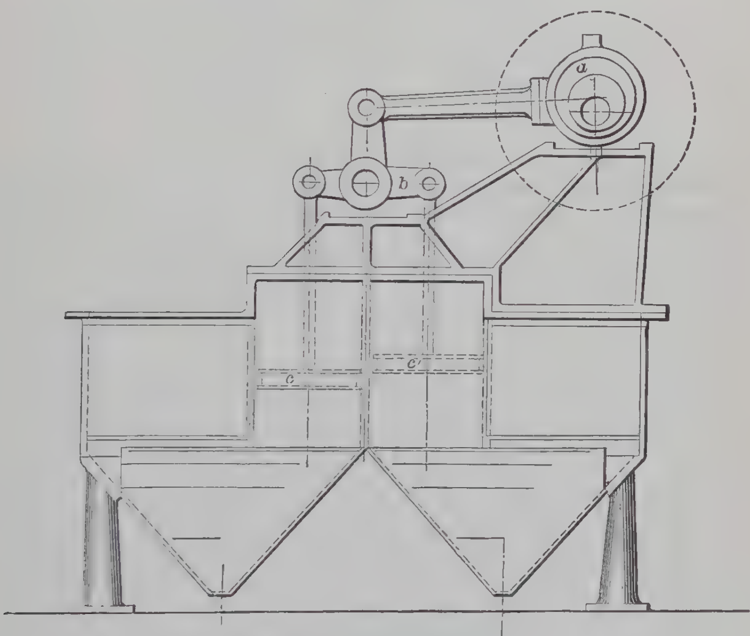
Klein Jig, Vertical Longitudinal Section.

eccentric; in a Klein jig, any number of plungers may be operated by one eccentric, whereby the horse-power required for a given number of jigs is materially reduced. Fig. 2 illustrates the method employed to effect this result by means of the eccentric, *a*, and the rocker, *b*, which operates the plungers, *c*, *c′*.

The use of compressed air plays a very important part in the operation of a Klein jig. The main advantages derived therefrom are (1) an increased, and (2) a cleaner product as compared with that of a machine in which water alone is the con-

centrating-agency. In Fig. 1 the space (f) acts as an air-receiver. An air-pipe (f–f, etc.), leading from this receiver, is run directly under the ore-caps below n and n'. The whistle-valves, s s', on this pipe, operated through x and y—y by an arm from the rocker-shaft, regulate the admission of air.* With every stroke of the plunger a puff of air is forced up through the ore-cap, effecting a clean and regular output of concentrates through the gates, n and n'. The usual pressure in the receiver varies from 25 to 35 lbs.

FIG. 2.



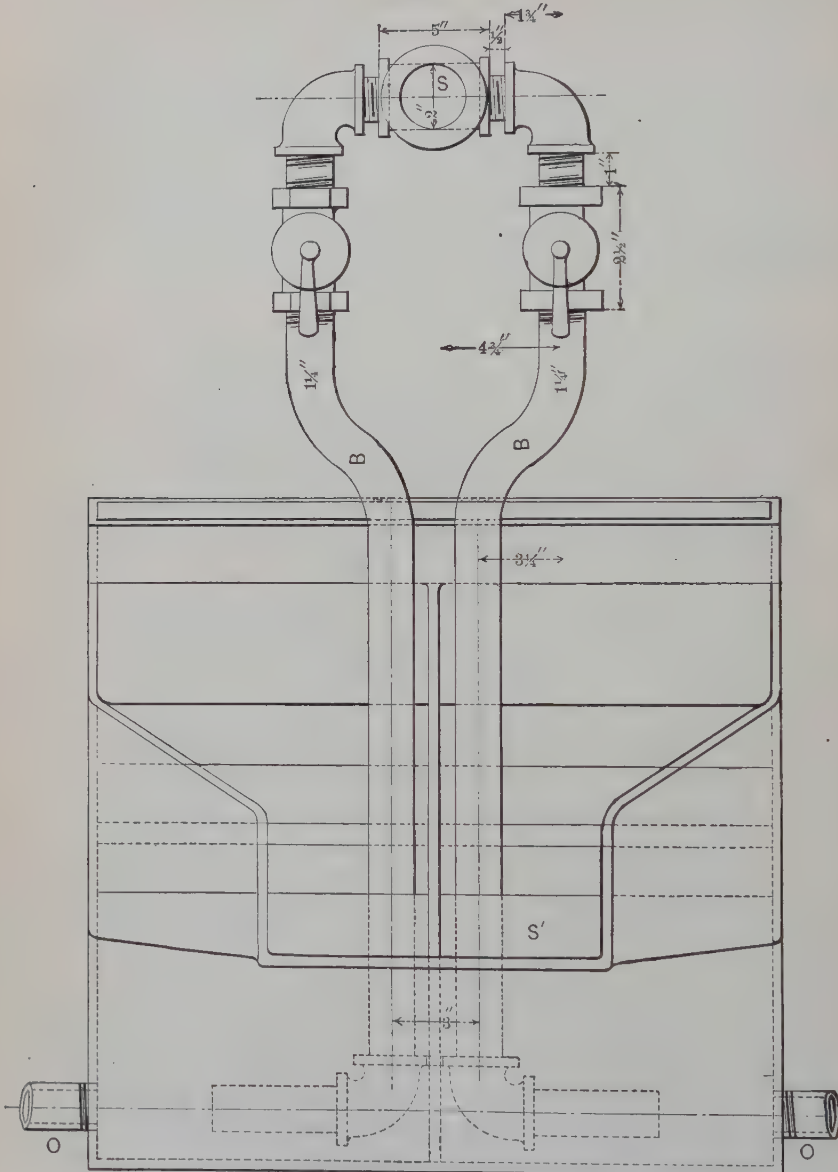
Klein Jig, End Elevation.

The eccentric can be regulated so as to give a throw of from 0 to 3 in., according to the class of ore to be treated. In SE. Missouri, where only galena-ore is concentrated, strokes of 0.625, 0.875 and 1.25 in. respectively, are employed for material of 4, 7 and 12 mm. grain; the number of strokes per minute averaging about 150.

At a plant in SE. Missouri, 27 of these jigs, of 4 compartments each, are treating from 450 to 500 tons of lead-ore every 24 hours. A test run of several weeks' duration was made on a lot of 2.5 per cent. lead-ore which had been thrown aside

* In Fig. 1, the connections from x and s s' to y—y are, unfortunately, not shown.

Fig. 3.



Klein Classifier, Front Elevation.

before the machines were installed; and the net returns showed that an extraction of 90 per cent. of the metal had been obtained, at a commercial profit.

Figs. 3, 4 and 5 show respectively the side and front elevations, and the plan, of the Klein classifier. The housing of

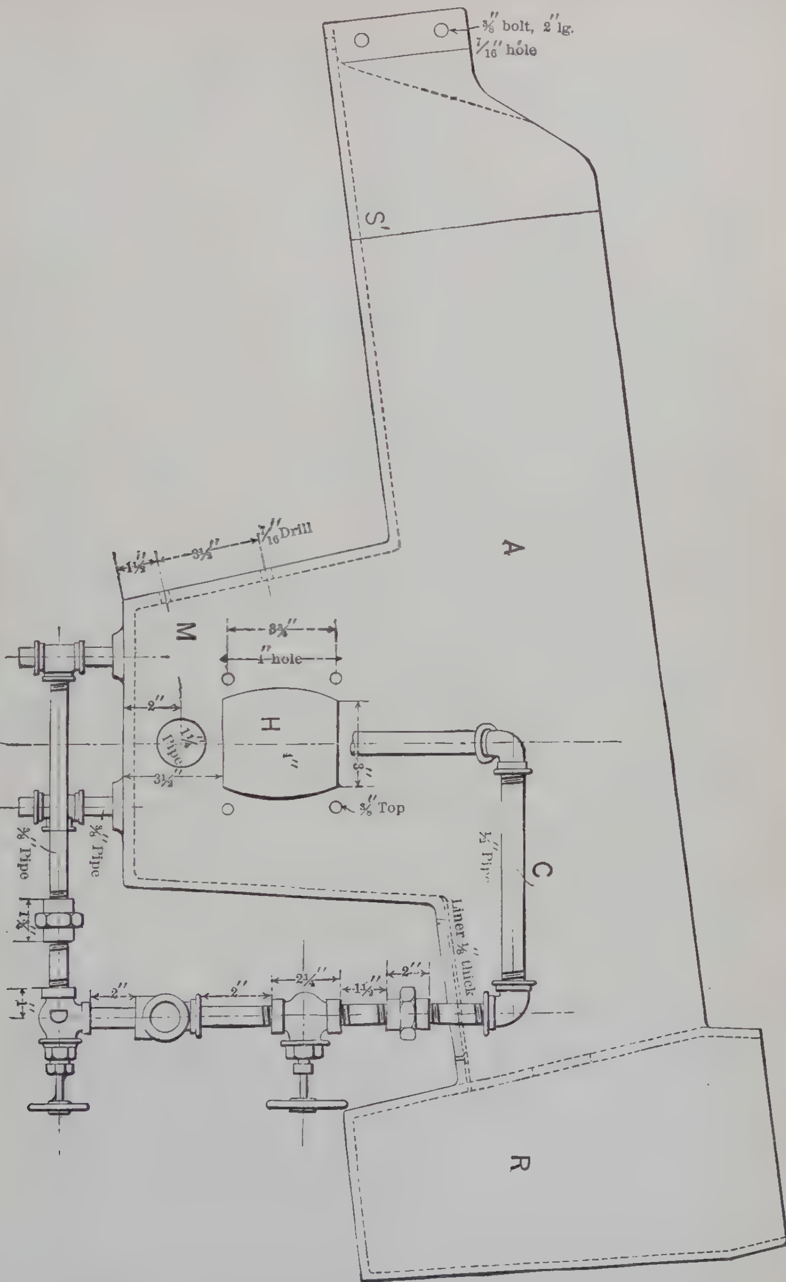
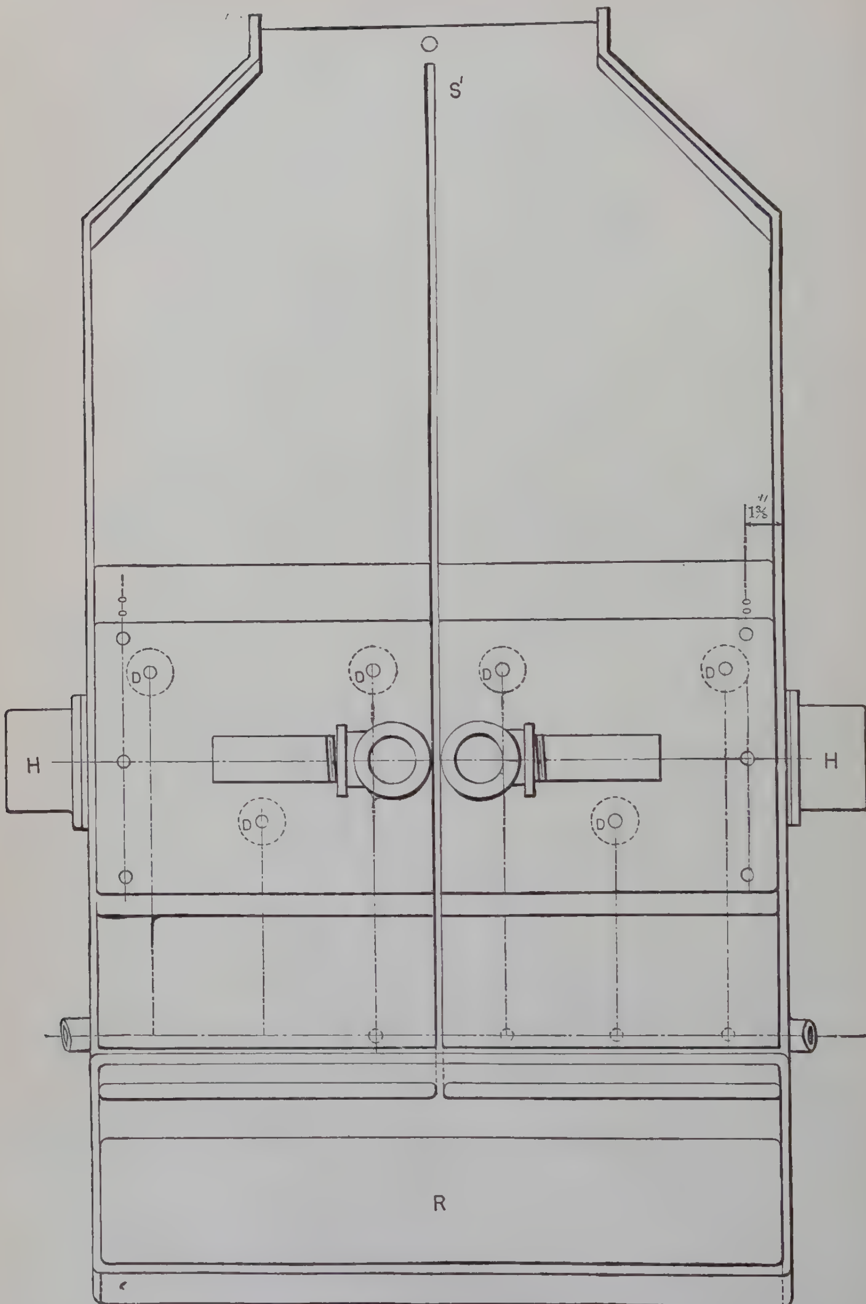


Fig. 4.

Klein Classifier, Side Elevation.

this machine is made entirely of iron, cast in one piece. This construction prevents leaks, and secures, what is almost impossible with a wooden housing, that the pipe-fittings (of which

FIG. 5.



Klein Classifier, Plan.

there are a considerable number) will remain permanently in position.

Compressed air plays an important part in the operation of this machine, as in that of the jig. The working-parts of the classifier are as follows: In Fig 3, the 1.25-in. pipes B, B, connected with the 2-in. pipe S, bring the main supply of water used in classifying the ore from a tank, elevated 15 ft. above the classifier. As the ore, mixed with water, comes from the trommels, it passes into the receiving chamber R, Figs. 4 and 5. As this chamber fills, the material flows over into the compartment M, Fig. 4, in which the classification takes place. In this compartment there are a series of air-inlets, both on the sides and bottom. The six circles marked D in Fig. 5 are the air-inlets on the bottom, each of which is regulated by a globe-valve. On the sides, air is inserted through the hoods H, H, Figs. 4 and 5, with sprays of perforated copper (also regulated by globe-valves), which blow directly against the water coming from pipes B, B, thereby causing a continuous agitation of the ore.

This use of air in combination with water is certainly a new departure in ore-classification; but it is, in my opinion, destined to become, in this branch of ore-dressing, as common as the use of water itself. Every bubble of air, as it comes from the bottom of the classifier, carries to the top a certain amount of fine material, which is washed into the outlet S′, Figs. 3, 4 and 5, while the larger particles, not thus acted upon, are left on the bottom, to find their way through the outlets O, O, Fig. 3. I have found that the air-pressure required for the jigs will also answer very well for the classifier.

When these machines have once been installed, their maintenance is an easy matter. They can be regulated with such delicacy that ores particularly rebellious to machines of this class may be successfully treated. The expense of repairs is reduced to a minimum by the simplicity of their structure; and, above all, they are easily tended.

Since the limits of this paper will not permit a thorough discussion of all details, U. S. Patents Nos. 674,169 and 674,269 (both issued May 14, 1901) may be consulted for a more complete description of these machines.

The Electrical Burner for Blast-Furnaces.

BY F. L. GRAMMER, PUEBLO, COLO.

(Mexican Meeting, November, 1901.)

In these days, when anthracite is less extensively used as a blast-furnace fuel than it was a generation ago, and managers endeavor to maintain regular and known ore-mixtures, the "freezing" of tuyeres, cinder-notch or iron-notch is infrequent; and, consequently, the oil-burner or "kerosene blowpipe"* is seldom employed; and furnace-foremen have, to a considerable degree, forgotten their former cunning and persistency in the use of the drill and sledge. Still, in starting new or abandoned plants with untrained labor, and in running some of our large 100-ft. furnaces, slips, resulting in very cold furnaces, may occur, even under experienced managers.

During my superintendence of the Cleveland, O., blast-furnaces, such a misfortune, owing to a dearth of trustworthy foremen, was experienced; and our electrician, Mr. Thomas Martin, proposed to open the tuyeres and cinder-notch by means of the heat of the electric arc. We have heard that the surface-cracks or marks developed in rolling heavy plates have been closed by electric welding, as by a soldering-iron, and also that an electric burner has been employed at some German blast-furnaces; but the experiment was quite novel to us; and I think it constituted one of the first, if not the very first, successful application of this device, for the purpose named, in the United States.†

* See Mr. Witherbee's paper on "Removing Obstructions from Blast-Furnace Hearths and Boshes," *Trans.*, xiii., 675; also Mr. Gayley's paper on "A Chilled Blast-Furnace Hearth," *Trans.*, xiv., 779; and Mr. Lee's "Note on the Opening of a Chilled Hearth with the Coal-Oil Blow-Pipe," *Trans.*, xv., 417. The last-named paper was presented 15 years ago; and I believe nothing on the subject has since appeared in our *Transactions*—a striking evidence of the changed conditions of blast-furnace practice.

† The principle was very clearly stated in 1891 by Prof. J. W. Langley (*Trans.*, xx., 252), who said that in the course of experiments upon fusion in an electric-arc furnace, it happened on several occasions that the arc from the end of a carbon

In the construction of the circuit, we attached one wire to a pipe, feeding a cooling-block of the furnace-wall, some distance from the point where the burner was applied. The current from this wire passed either through the crucible or through the circumferential shell. The other wire, after running through a resistance-coil immersed in a barrel of water, was attached to clamps holding the carbon, the latter being inserted in an iron-pipe, provided with a wooden handle, and applied at the desired point by the goggled operator.

Our first experiments were not very successful. We used 1.5-in. carbons, 1.5 ft. long, not being able at the moment to obtain larger ones. Subsequently, we had carbons made 4 and 6 ft. long; and with these we burned a hole through 18 in. of cold iron in 5 minutes. A current of from 400 to 500 ampères did the work; but 1000 ampères (at 80 volts) gave better results. Our two dynamos were General Electric, with 110 K.W. capacity and 220 volts. We reduced the voltage by means of a resistance-coil of German silver wire.

The results were so satisfactory that permanent wires were strung up to the furnaces;* and "hard holes" at tapping-time, requiring slackening of wind, are now an evil of the past.

Water-blocks sometimes leak, and flood a side of a furnace, closing several tuyeres and causing one-sided working. But by putting blanks on the penstocks temporarily out of use, the blast can be kept on the furnace while the closed tuyeres are burned open. Several furnaces on the Lake fronts used it successfully, after hearing how it had assisted us.

The electric current employed is not dangerous to the workman; and the apparatus, unlike the oil-blowpipe, is always ready for service. It can be applied instantly to a black, cold surface, without the need of any blast-pressure—a boon which will be appreciated at single stacks, where the freezing of the tuyeres may have made it difficult to get the necessary pressure, by affecting the gas-supply to the boiler-house.

---

rod struck squarely in the center of a lump of steel about as large as a hen's egg, and that "in a very few seconds that arc would bore a hole through that piece of steel, the corners of the steel being still so cold that, when seen through the dark spectacles that one had to wear, they appeared to be black." I am informed that a similar device has been used by safe-robbers.

* The low potential requires a heavy copper wire.

The saving in oil, worn-out men, drills and time, commends this simple and effective burner as the best.

We may say of this apparatus what used to be said of a dress-coat or a pistol—that "it is not needed often, but when it is needed, it is needed awfully!"

Plants not equipped electrically can use the power of a neighboring municipality or other works, employing a rotary transformer to obtain the desired current.

Both the holder of the burner and the curious spectators should wear the darkest glasses, such as are worn by heaters—or twelve hours of great suffering will be the penalty.

A Bryn Mawr graduate, in describing the Bessemer converter, which she had just seen for the first time, remarked that she was much impressed with the "Intense Molecular Activity" there displayed. This pedantic but accurate description applies with still greater force to the electric-arc burner, as those who are so foolishly enthusiastic as to watch it with unshielded eyes will be forced to confess.

The Operation of the "Hole-Contract" System in the Center Star and War Eagle Mines, Rossland, B. C.

BY CARL R. DAVIS, E.M., ROSSLAND, B. C.

(Mexican Meeting, November, 1901.)

I. General Remarks.

The cost of mining during the past history of these mines has been excessive, principally by reason of the inefficiency of labor under the wage-system. The amount of labor performed per man was unsatisfactory; and Mr. Edmund B. Kirby, the general manager, decided to adopt the contract-system as a remedy. For this purpose the method now in use was devised by the writer (then and now the superintendent), as best adapted to the local conditions. On March 12, 1900, this system was presented to the miners of the War Eagle and the Center Star. The issue remained unsettled for several weeks,

during which the mines were closed. On April 5 an amicable understanding was reached, and the miners resumed work on the new terms. The system was introduced by degrees; and the results of a year's trial have shown it to be an unqualified success.

The veins of this district have been formed by replacement in fissures of the shear-zone type, ranging in width from several feet to 100 ft., or more, and fairly regular in strike and dip, through the main mass of Red mountain, which consists of augite-diorite, a dark, tough, basic eruptive rock.

Between the limiting walls, the vein-material ranges from a hard silicified mass, with only scattering mineralization, to an almost solid sulphide, mainly pyrrhotite, with a relatively small amount of chalcopyrite and pyrite. Consequently the rate at which drilling proceeds varies considerably within short distances; but the *monthly* average of the number of feet drilled per machine per shift does not vary more than 5 per cent.; thus allowing an accurate determination of the price to be paid per foot of drilling.

Generally speaking, the vein-material and the surrounding country-rock are very hard and tough, making it unnecessary to timber the headings. In fact, stopes up to 50 ft. in width can be made without timbering. Another feature bearing upon this problem is the complication of the geological structure by numerous dikes and faults. The pay-shoots are very irregular in outline, sometimes so much so that the payment of contractors in the stopes by the fathom or any other unit would be impossible, by reason of the difficulty of measuring exactly the volume of rock broken during a given period. The determination of the amount of ore stoped by making a mine-car the unit of measurement for either weight or volume was considered, but had to be abandoned on account of the impracticability of keeping the ore broken by each set of contractors separate, since, at times, the ore broken by several sets of contractors is drawn off through the same loading-chute in the mine.

II. Contract-Systems.

Two methods are employed in measuring the amount of work performed:

1. Measurement of the number of linear feet of advance.

This method, commonly employed in all parts of the world, is applicable to headings only, such as drifts, cross-cuts, raises, winzes, and shaft-sinking. In these mines, where payment is made per running foot, the contractors are charged for the explosives, which are furnished to them by the company at cost. This results in greater economy in the use of explosives than is secured by the practice, followed in some western mines, of supplying powder, etc., free. Under such an arrangement the men are not as careful as they would otherwise be to put their holes in the most advantageous positions; and, substituting powder (which costs them nothing) for labor, they make the total cost of the work unnecessarily large. In raises and winzes, the necessary timbering is performed by the company; but in shaft-sinking the contractors place the sets in position, subject to the approval of the mine-foreman. Blasting is done by the contractors at any time.

2. Measurement of the number of feet of holes drilled. This system, first adopted for use in the stopes, has been shown by experience to possess several advantages over the one above described; so that, in many cases, it is now used even in drifting and cross-cutting, and deserves to be here more fully described.

III. Details of the Hole-System.

The underground work is carried on by two 8-hour shifts, arranged as follows: morning shift, 7 A.M. to 4 P.M., with an interval of one hour for dinner; afternoon shift, 4 P.M. to 1 A.M., with one hour for supper. The men are raised from and lowered into the mine on their own time (*i.e.*, before and after the terminal times given), making eight hours the actual working-time. In shaft-sinking and in occasional headings, three shifts are employed, and the work is carried on continuously during the 24 hours. With the exception of the main shaft, in which the contract includes 12 men, contracts are generally let to four men, working in pairs for two 8-hour shifts daily. Contracts are verbal, not written. No sub-contracting is permitted, and the men share equally in the profits of each contract. In case of sickness a contractor must provide a substitute. If any contractor wishes to leave before the expiration of the contract, he is paid his share of the net earnings according to his pro-

portion of the total number of shifts worked. Prices are fixed and contracts are let at the beginning of each month.

On beginning work, each set of contractors is supplied with a tool-chest, provided with lock and key, containing all necessary tools and supplies for machines, for which a receipt is taken. At the expiration of the contract the tools are inventoried, and those missing are charged to the contractors. On the other hand, there is no charge for breakage, if the broken tools are turned in and new ones are issued. Machine-drill repairs are made by the company; but it is understood that breakage through neglect or carelessness is sufficient cause for discharge. When desired, a box for steel drills is placed at some convenient point on the level. This box has two compartments: one for sharp steel, placed therein by the tool-packer; the other for dull steel, which the tool-packer collects while replenishing the "sharps."

The first duty of the miners on the morning shift is to pick down the loose ground left from the blasting. When the "back" has been made secure, the machines are set up, and drilling proceeds continuously during the two 8-hour shifts. The location of the holes to be drilled is marked, and their approximate depth and direction are indicated by the foreman. Misplaced holes, or those drilled too deep, are not accepted by the foreman as entitled to be paid for; and an occasional check of this kind is all that is necessary to insure good work. Drilling proceeds without interruption during working-hours, and is only stopped on the night-shift in time to allow the contractors to take down the machines, clean out the holes, and leave them in shape for the blasting-crew, before leaving the working-faces at 1 A.M. The number of feet of holes drilled is measured at the end of the shift, at which time a record of the measurement is furnished to the contractors, and a duplicate is delivered at the office.

The blasting-crew works between the hours of 1 A.M. and 7 A.M., and its work consists in loading and blasting the holes drilled by the miners. This effects a considerable saving in the consumption of explosives, since these are handled by a few picked men only. Another advantage of this method is that it involves no loss of time by miners and muckers (shovelers) in waiting for the working-faces to become clear of smoke.

In headings, the details of the work are, in all essentials, the same as previously explained with respect to the stopes. The number, direction and depth of the holes are outlined by the foreman or shift-boss; but when contractors have become familiar with the ground, little direction of this kind is needed, the work being practically the same each day. The working-hours are the same as in the stopes. On entering the heading in the morning, the miners pick down the roof, put up the horizontal bar supporting the machine-drill, and proceed with the drilling of the holes in the upper part of the face. While drilling is carried on, the shovelers are removing the broken rock from the previous blast. By the time this has been cleared away, the machine-men are ready to take down the bar, set it again in a horizontal position near the floor of the drift, and drill bottom-holes or "lifters." These being finished, the machine is taken down; the holes are cleaned out; and a floor is laid for the shovelers. Everything is then ready for the blasting, which, as in other parts of the mine, is performed between 1 and 7 A.M. by a special crew.

In headings where a certain number of holes have to be drilled before the whole set or "round" can be blasted, the difficulty with the "hole-system" (*i. e.*, the system of payment according to linear feet of aggregate drilling) is in making sure that the contractors finish this work before blasting-time, in order that they may not have to lose working-time during the blasting, and thus that they may be kept continuously employed. This difficulty is met, either (*a*) by increasing or decreasing the depth of the holes to be drilled; or (*b*) by having one or two spare headings or stoping-breasts in which contractors can utilize their extra time. The latter expedient is to be preferred, for the reason that, to secure the best effect, the depth of drill-holes ought to be determined on other grounds than that of the time required to drill them.

Advantages of the Hole-System.

1. Its applicability in stoping, where the ore-shoots are irregular in outline, and measurement by weight or volume of the ore broken cannot be easily made.

2. Within certain limits, the number of machines in any one stope can be varied at will; and there is no difficulty such as

would arise from the necessity of keeping separate the work done by each set of contractors.

3. The system is extremely elastic; that is, the same set of contractors can be employed in different headings or stopes, without any resultant confusion in measuring the work performed.

4. Blasting is done only in the interval between 1 A.M. and 7 A.M., and the miners and shovelers are not kept idle, waiting for the smoke and gas to be cleared away from the working-faces.

Disadvantages of the Hole-System.

As above shown, this system has been perfectly satisfactory in stopes. In headings, the disadvantages, as compared with the linear system of payment per running foot, are as follows:

1. Two 8-hour shifts only are employed under the hole-system; while by the system of paying according to the linear progress of the heading, three shifts may be employed daily, and blasting done at any time, thus often increasing the rate of advance, which may be a matter of supreme importance in opening new ground, etc.

2. The difficulty, already discussed, of so laying out the work that the round of holes may be completed in the two daily shifts, without an undue loss of time to the contractors.

IV. Economic Results of the Hole-Contract System.

The following tables show the saving effected by the substitution of the contract- for the wage-system. In this connection I may add that the advantage thus gained by the employer is not lost to the workmen. The miner now receives daily from \$4 to \$4.25, as against \$3.50 under the wage-system.

Table I.—*Comparative Cost of Stoping.*

	Contract (Hole-) System, Per ton.*	Wage-System. Per ton.†
Drilling,	\$0.356	\$0.750 (Drilling and Blasting)
Blasting,	0.021	
Explosives,	0.100	0.115
Total,	\$0.477	\$0.865

* Calculated from 49,849 tons of ore stoped.

† Calculated from 13,818 tons of ore stoped.

TABLE II.—*Comparative Cost of Development-Work.*

	Contract (Hole-) System. Per foot.*	Wage-System. Per foot.†
Drilling,	$5.36	$8.36
Blasting,	0.68	
Explosives,	2.75	2.78
Total,	$8.79	$11.14

Equally important with the saving, per foot or ton, shown in Tables I. and II. is the increased speed with which shafts have been sunk, and headings have been driven. For it is clear that, other conditions remaining the same, the output of the mines is governed by the time required to open new ground in depth by sinking and driving levels, etc. In drifting and cross-cutting, the average rate of advance per month has been increased from 50.8 ft. under the wage-system to 97.5 ft. under the contract-system; this comparison being made on the basis of two shifts (4 men) per day, and a 30-day month. In shaft-sinking, calculating on a basis of 3 shifts (12 men) per day, and a 30-day month, 555.5 ft. of work done under the contract-system, compared with the last 200 ft. done under the wage-system, show the rate of advance per month to have increased from 27.2 ft. to the present average of 58 ft.

Influence of Country-Rock on Mineral Veins.

BY WALTER HARVEY WEED, U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C.

(Mexican Meeting, November, 1901.)

AMONG the many causes of that perplexing feature of mine-exploitation, the unequal distribution of the ore, the influence of the country-rock upon the vein-contents has long been accepted as an important factor in certain districts, but the general application of the theory has not been proved. It is now possible to obtain trustworthy data with which to test the theory, and either to confirm or to overthrow this time-honored

* Calculated from 1244 ft. of headings driven.

† Calculated from 1377.5 ft. of headings driven.

tradition. By the searching methods of modern petrography and chemistry, rock-determinations are now scientifically made, while the examination of thin sections of ores supplements field and laboratory study, and affords conclusive evidence of the paragenesis of the ore-minerals.

In the great mass of data, regarding mineral deposits, accumulated during the past century, there are some facts which stand the test as to reliability; but the greater part are not available for use in this discussion. Within the last twenty years, however, many able workers have contributed careful and accurate accounts of various ore-deposits; and it is by the facts given in such papers, and by personal experience, that I have become convinced that there is in some districts a true relation between the country-rock and the mineral contents of the veins.

My own interest in the subject arose from the observation of a number of striking instances of the variation of vein-contents with the nature of the enclosing rock. Having already recorded certain observations of this kind, I venture to present in this paper further notes, together with a few facts from the literature of the subject, which seem to prove the correctness of my view. It is apparent that if the relation holds true, though in limited districts only, it will be of great practical interest to the miner, and will confer upon the geological survey of a mining district a new value, rendering it, in fact, an almost indispensable preliminary to the extensive working of large properties.

The influence of the enclosing rocks upon mineral-veins evidently affects both the vein-structure and the vein-filling. The first effect is physical; the second is mineralogical or, primarily, chemical. The first has been but lightly touched upon, if noticed at all, by writers on mining geology. The second has long been recognized as a fact in a few well-known examples; but, although many attempts have been made to show a relationship between certain ores and definite rock-types, the correlations have been of local value only.

I. Influence of Rocks on Vein-Structure.

It is self-evident that in most mineral deposits the rocks must have been either porous or so fractured as to permit the circula-

tion of underground waters as a preliminary to vein-formation. It is also evident that according to the varying hardness, toughness, etc., of the rocks, the fissures found in them will vary in character, and the physical aspect of any resultant ore-deposit will be governed by the nature of the rock.

Fissure-veins, and, indeed, all forms of ore-deposits, are affected in size and shape, and probably to some extent in richness, by the character of the fissure or fracture in which the vein was formed. Experience shows that a vein often varies greatly in structural characters, such as width, uniformity, presence of splits and horses, etc., in passing, whether horizontally or vertically, from one rock into another. Thus the vein may pinch out in a very tough rock, expand in a more easily shattered material, become dissipated into a stockwork in brittle, shattered rock, or become lost entirely in a shale. In easily soluble rocks, like limestones and dolomites, the original character of the fissure may be modified by solution, and thus the original effects of its force may be masked. This case stands in such intimate connection with the mineralogical effects due to the nature of the rock that it is best considered in the second part of this paper. The irregular deposits formed in limestones show the influence of the enclosing rock on the form of the deposit to an even more marked degree than fissure-veins. The fissures which, in traversing a tough rock, are clean cut, may, in passing into a more easily fractured rock, or one netted by fine jointing, produce a mass of shattered material in which the mineral is so disseminated in minute and numerous fissures that the entire mass must be extracted. Often the vein, solid and continuous in one rock, splits up, forming horses or droppers, or, if very extensive, becomes a zone traversed by many small parallel threads and stringers, too small to be worked. This is discussed by Prof. Beck, in his recent book,* from which Fig. 1 is taken.

In the Guadalupe mine, Chihuahua, Mex., a vein, carrying a solid ore from 10 to 40 ft. wide, changes eastward into many small branches, too small to be worked, though the richness of the ore in them may be unchanged.

Where veins traverse foliated rocks, such as gneisses and

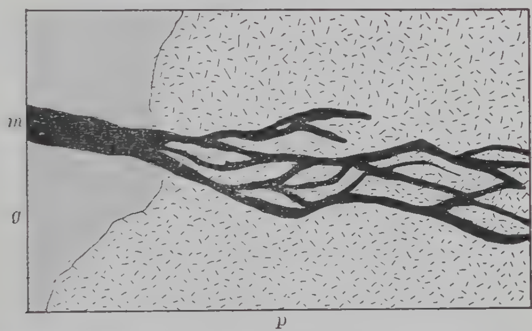
---

* *Lehre von den Erzlagerstätten*, Berlin, 1901, p. 135.

schists, the original fissures may have been due to a very slight movement along the plane of schistosity, and the result may be linked veins, composed of numerous connected lenses, such as are commonly found in the Piedmont area of the Carolinas. If the movement is distributed over several folia the vein is not a simple one, but consists of a series of lenticular masses overlapping each other, and these may occur in a zone; so that the "vein" may be several hundred feet wide.

It is evident that, since different rocks break in different ways, the character of the fissures formed in them will depend on the country-rock. Excellent examples of the various effects due

FIG. 1

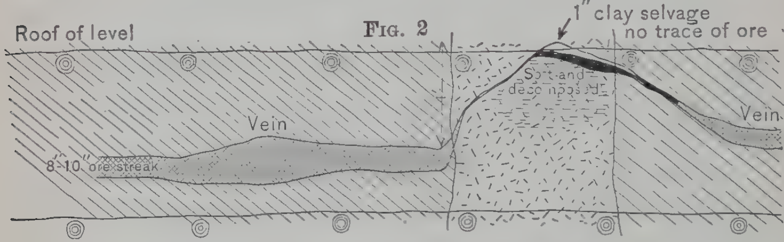


Scattering of the Gottlob Vein in Quartz-Porphyry, in the David Shaft, near Freiberg, Saxony. *g*, Gray Gneiss ; *p*, Quartz-Porphyry ; *m*, Vein.

to the texture, cleavage, hardness, and other properties of the rocks, are to be seen in the silver-lead mines of Neihart, Montana, where steeply-dipping metamorphic rocks are cut by a large and very irregular intrusion of diorite, and both are cut by later intrusions of rhyolite porphyry. Well-defined fissure-veins cross all these rocks. The metamorphic rocks consist of alternating bands of feldspathic gneiss with softer, more schistose micaceous rocks, and, more rarely, tough amphibolites. The veins cross these rocks at nearly right angles to the schistosity. The underground workings show the veins to vary somewhat in width and in the relative abundance of included rock-fragments, when they pass from one belt of feldspathic gneiss to another, and more markedly when they pass into the more schistose rocks; but the change is so abrupt where the amphibolites are encountered that the miners say the vein is faulted. In fact, the tough nature of this rock has

sometimes deflected the vein, and has always, in the instances observed, narrowed it from 7 to 8 ft. in width of good ore to a foot or more of barren gangue. Fig. 2* is an example from

FIG. 2

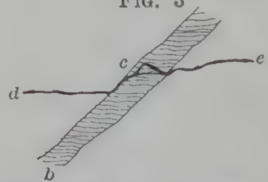


Section of Level, Showing the Florence Vein, Neihart, Mont., Crossing an Amphibolite Dike in Metamorphic Schists.

Neihart, where the veins, passing from schist into Pinto diorite, a peculiar igneous rock of coarse grain and texture, are invariably narrowed, but well-defined. In the rhyolite porphyry, the same fissures lose their compact character, ramifying into a network with shattered rock between, which dissipates the ore; so that, while the surface-workings are commonly rich, the ore-body does not pay in depth, owing to the large amount of waste.

The same phenomenon is described by De la Beche.† The vein shown in Fig. 3 encounters an elvan dike *b*, in passing from *d* to *e*, and passes up the wall of the dike, scarcely showing as a vein alongside of the dike until it crosses the dike at *c*, and continues on through the slates.

FIG. 3



Fissure Deflected by Dike (De la Beche).

At Butte, Montana, the veins occur in a coarse-grained granitic rock (a quartz-monzonite) with intrusions of aplite granite, and dikes of porphyry. Where the veins cross the porphyry they are narrower to a marked degree; and the same is true

* From the *20th Ann. Report of the U. S. Geol. Survey*, Part III., p. 426.

† *Geological Observer*, Ed. of 1851, p. 755.

of the aplite. In part this is due to a more intense metasomatic replacement of the granite than of the other rocks,—a fact which will be discussed in describing the influence of the wall-rocks on the filling. It is quite evident that the rock-character has influenced the fissure.

The copper-veins at Virgilina, Va., which occur in metamorphic schists formed from old igneous rocks, show a structural feature common in the veins of the Southern States where the fissure crosses the rocks at less than ninety degrees to the schistosity. In such cases the veins show many spurs running off for short distances from the vein along the planes of the schist. The Blue Wing mine, at the locality mentioned, shows a diabase dike cutting the schists; and where the vein crosses this rock it is narrowed and becomes a mere zone of plated rock. The spurs seen in some veins in granite are evidently the result of cross-fissures or joints, and not to be considered as a function of the rock itself.

Where the veins pass from schists into quartzite, as may be seen at Neihart, there is a marked change in their character. This is well seen at the Big Seven mine, where a well-defined vein changes to many small fissures with shattered rock between. At Frenchtown, a small settlement east of Deer Lodge, Montana, the veins in andesite-porphyry are strong and well-defined fissures, but do not cut any other rock; hence direct comparison cannot be made. At the Porphyry Dike mine, south of Rimini, Montana, the veins are small and tight in the granite, and open out in the rhyolite into wide fissures, ill-defined, and really more like bands of shattered rock.

This variation of fissures in different rocks is especially well shown at Cripple Creek, Colo., as described by Penrose,* and alluded to by Van Hise.† In hard rock the fissures are sharp and clean-cut breaks, but in the soft rock they are ordinarily mere series of very small cracks, constituting what Van Hise calls "distributive" faults.

In slates the vein is commonly well-defined, as at Copperopolis in Montana, and Parral, Mexico. In the Cœur d'Alène, in Idaho, the veins cross slates and quartzites, and present only

* "Mining Geology of Cripple Creek District," by R. A. J. Penrose, Jr., 16th *Ann. Rept. U. S. Geol. Surv.*, 1894–5, Part ii., p. 144.

† "Some Principles," etc., *Trans.*, xxx., 35.

those minor peculiarities which might be expected in passing through such rocks—in fact, there is less change than one would naturally look for.

Throughout the Appalachians the veins show a clustering of quartz-lenses whose ends overlap. These have been called "linked veins" by Becker, and "compression-veins" by Stretch. That they are the result of the foliation of the schists is generally accepted. Where the lenses are parallel to the foliation there is reason to believe that they are a result of the spreading apart of the folia by movement. When the quartz lenticules lie across the vein, as they often do in the Carolinian veins, presenting the structure figured by Rickard* for the Victorian veins, it seems that the quartz-filled spaces result from a rending of the rock between two parallel fissures. Many of the minor peculiarities of vein-walls are due to the character of the rocks, but these are not intended to be treated here. Rickard has already described many features of vein-walls due to varying rocks.

The study of a large number of mines all over the country shows that, although no rule can be laid down for all localities, each district will present certain peculiarities. In Montana, the rhyolites are not favorable for well-defined constant veins, as the rock is too easily shattered. The granular rocks vary in effect; and the more basic forms, carrying augite or hornblende, are favorable for well-defined fissures.

As it is not my intention to do more than call attention to the differences in fissuring in varying rocks, no further mention of such peculiarities will be presented here. It is evident, however, that where a single mass of rock varies in texture, as, for example, the granite core of Castle Mountain,† Montana, in which continuous exposures show the rock passing from granite through intermediate gradations into rhyolite-porphyry, the vein-fissures will vary with the physical characters of the rock.

II. Influence of Country-Rock on Vein-Filling.

Where a vein, passing through two different rocks, carries one set of ore- and gangue-minerals in one rock, and another

* *Trans.*, xxi., 686–713.

† Weed and Pirsson, "Geology of the Castle Mountain Mining District," *Bull.* 139, U. S. G. S.

set in the other, there is a strong presumption that the variation in the enclosing rock has caused the variation in the vein-materials. Similarly, if in given districts one set of vein-minerals always occurs with a certain kind of country-rock, and another set with another kind, it is probable that such association is genetic, and not accidental.

For many years there has been a widespread belief among mining geologists and engineers that igneous rocks are an almost invariable accompaniment of productive ore-deposits of the precious metals. Whether the igneous rocks be regarded as the actual source of the metal, or as the cause of fissuring and ore deposition by reason of dynamic disturbance, the result is genetically due to the volcanic forces. Prof. Vogt has recently given us, in his able and instructive paper,* a *résumé* of his studies, and Prof. Kemp has shown† both the competency of the igneous rocks themselves as a source of supply and of the intrusives as a source of energy. It is not this phase of the subject that I propose to discuss, but the time-honored question of the influence of wall-rock upon the mineral contents of the vein. Many students of ore-deposits, familiar with the common occurrence of galena-ores in limestone, and the changes in mineral character of the Cornish veins with change of rock, have sought to establish a relation between certain rocks and certain ores. While such a relation seems to prevail in a few districts, no general law has been established by these attempts.

Conditions Governing the Relation of Country-Rock to Vein-Contents.

In considering the relations between country-rock and vein-contents, the following premises are assumed:

1. Vein-filling may be the result of (*a*) the filling of open fissures, (*b*) of replacement, or (*c*) of both filling and replacement.

2. The ore- and gangue-minerals of all these types vary. Lindgren has divided veins filled by metasomatic replacement into eleven classes, and shows that the chemical processes involved were very different in each case. It is made certain by the study of altered wall-rocks and of mine-waters that the

* "Problems in the Geology of Ore-Deposits," *Trans.*, xxxi., 125.

† "Rôle of the Igneous Rocks," etc., *Trans.*, xxxi., 169.

mineral-forming solutions have varied greatly in character. Moreover, some veins have been opened after formation, and new minerals have been introduced by later solutions.

In veins the material of which is well crustified, or is known to be the result of the filling of open fissures, a marked influence of the wall-rock on the contents of the vein would not be expected. In the majority of veins, however, there is evidence of more or less metasomatic replacement; and it is evident that the nature of the wall-rock will be an important factor in the chemical reactions of the processes of replacement. It should be remembered, however, that the evidence of many districts shows that veins of different kinds and ages may form in the same rock, and hence it is not to be expected that any general conclusions, applicable to all veins, can ever be reached.

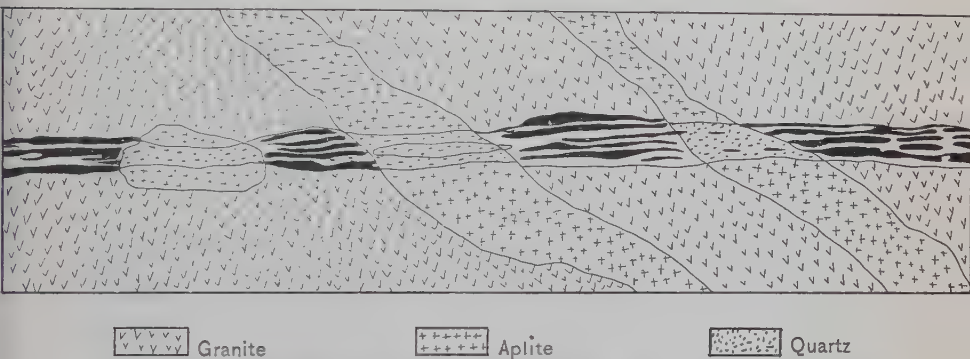
Examples.

Butte, Montana.—In the typical silver-veins of this district the filling consists of quartz, showing well-marked "comb"-structure, with rhodonite, rhodochrosite, pyrite, zinc-blende and silver sulphides. The structure is clearly that of the filling of open fissures. These veins occur in the normal Butte granite, a quartz-monzonite, and in the Bluebird granite, which is an aplite. There is, however, no perceptible difference in either the character or the tenor of the ore between the veins in the aplite and those in the normal granite, or in the parts of the same vein where it cuts the two rocks. In the copper-veins, on the other hand, there is a marked difference. These are of undoubted metasomatic origin, and were formed by the replacement of the rock along fracture-planes. In the copper-area, the veins cut both the two rocks previously mentioned and also a quartz-porphyry, which I have named the Modoc porphyry. In the Butte granite, the veins are commonly rich in copper; in the Bluebird granite they are almost equally wide and strong, but are lean, and composed chiefly of quartz, with comparatively little pyrite and copper. In the porphyry, the veins are narrow and lean. There are so many instances in which the same veins can be seen cutting all three rocks that there can be no doubt as to the correctness of these conclusions. The vein-filling consists of quartz which shows no comb-structure, with pyrite and various copper-min-

erals, of which chalcocite, enargite and bornite are the most common. The walls on each side are much altered, and the less altered rocks at some distance from the veins show the ferromagnesian silicates altered to pyrite.

The relative richness of the veins in the Butte granite is believed to be due to the basic character of the rock, and its greater content of the easily replaceable iron silicates. The rock is a quartz-monzonite, the composition of which has been carefully calculated from chemical analyses of the rock, and of the biotite and hornblende isolated from it, and from microscopic analysis of the rock as well.* This shows it to contain 15.26

Fig. 4



Ideal Plan of Conditions in a Copper-Vein at Butte, Mont., Passing from Basic Granite into Aplite Masses. The solid black represents high-grade copper-ore, when the vein is in basic granite.

per cent. of hornblende and 4.22 of biotite. There is a little augite also. The aplite contains over 10 per cent. more silica than the rock just noted, no hornblende, and very little biotite. The Modoc porphyry also has, when fresh, a very little mica, and is as high in silica as the aplite. Mr. H. V. Winchell has called my attention to the condition shown in the diagram, Fig. 4. In the case here given as a general type, the vein is workable only in the Butte granite.

A study of thin sections of the rock adjacent to the ore shows that the hornblende is the first mineral to be altered into ore, and that the bunches of this mineral form the nucleus for a more or less complete replacement of the entire rock. The

* "Granite Rocks of Butte, Mont." W. H. Weed, *Jour. Geol.*, vii., 737, Nov.–Dec., 1899.

general principles of this metasomatic replacement are those given by Lindgren.* It is probable that the alteration now seen in the wall-rock, with its nests of pyrite replacing the biotite and the hornblende, may present the earlier stages of the metasomatic process, and that the pyrite thus formed was not only the nucleus for a further deposition of pyrite, but that the pyrite itself was the precipitating agent for the copper-minerals, as has been shown to be the case in the secondary enriched ores. In the aplite there is more quartz and less pyrite, and the latter mineral is noticeably poor in copper. The same general statement also holds true for the porphyry.

The Dolcoath mine of Cornwall is perhaps the best-known example of a vein, the mineral contents of which vary with the nature of the enclosing rocks. As described by many writers, the veins carry copper-ores in slate and tin-ores in granite. Stretch† gives a further example of argentiferous galena with its usual associated blende and pyrite in a decomposed plagioclase porphyry, changing to auriferous arsenopyrite in the underlying granite.

Cornwall.—Fissures crossing the contact of granite or other intrusive rock with sedimentary rocks are not uncommonly productive, when the district is metalliferous. This is very marked in the Cornwall mines, where bunches of ore occur at the junction of granite and schist. De la Beche‡ mentions fissures traversing schists and passing through a dike of porphyry (elvan) some 300 ft. thick. The vein above the dike carried little ore; in the elvan, ore was abundant and rich, but became poor again in the slates beneath (Fig. 5). This occurrence of ore-bunches where fissure-veins cross such dikes has always been known to the Cornish miners. When the lodes pass into the dikes, they are often branched and split, as shown in Figs. 3 and 6 (after De la Beche); and in such cases, though the total amount and richness of ore be the same, the vein may not pay to work, on account of the large amount of waste.

Pontgibaud, France.—Here the silver-lead veins occur along fractures within granulite dikes, and on the line of contact with the gneiss country.

* "Metasomatic Processes in Fissure-Veins." *Trans.*, xxx., 578.

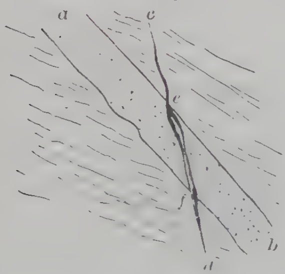
† "Prospecting, Locating and Valuing Mines," p. 135.

‡ *Geol. Observer*, Ed. of 1851, p. 778.

"When the dike diminishes in size the ore decreases in width; when the vein penetrates into the gneiss, the ore disappears. The best ore is associated with the kaolinization of the feldspar of the granulite; and when the latter becomes hard and unaltered in depth, the ore pinches out."*

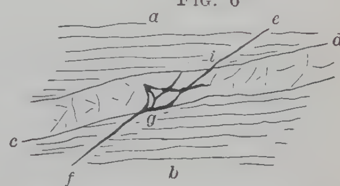
Rico, Colorado.—Rickard also mentions the veins of rich gold- and silver-ores at Newman Hill, Rico, Colo., as "noticeably affected by the character of their rock-walls." There is a marked change in passing from limestone into sandstone; and generally the veins are richest in the darker-colored sedimentary rocks. The interdependence between country-rock and ore is briefly discussed by Rickard, who adopts Cotta's ex-

FIG. 5



Section across Wheal Alfred, Gwinear, Cornwall. Rich ore occurs in the dike only. (From De la Beche.)

FIG. 6



Vein Split in Traversing Jointed "Elvan" Dike. (De la Beche, *Geol. Obs.*, p. 779.)

planation that the physical texture and chemical composition of the country-rock affect the deposition of ore, and declares that it was undoubtedly the carbonaceous matter of the rock at Rico which acted as a precipitant. This example differs, therefore, from that of Pontgibaud, where feldspar has been replaced by silver-bearing galena.

Neihart, Montana.—At this locality the veins show a remarkable variation in richness, corresponding to differences in the wall-rock. Mr. Robert H. Raymond, the former manager of the Diamond R. properties, found that the veins were barren in the dark-colored gneisses, and held ore-bodies in the pink or white feldspathic gneiss. My own observations enabled me to confirm this in a general way, and also showed that in amphibolite the vein was barren as well as narrow, and that no workable ore-bodies had been found in the diorite. In quartzite and

* T. A. Rickard, "Vein Walls," *Trans.*, xxvi., 200 (1897).

in the intrusive rhyolite porphyry the veins have proved rich near the surface, but the values have gone down but a few yards. It is believed, however, that this is because of structural conditions, with secondary enrichment of a shattered zone, rather than because of a mineralogical condition due to the nature of the enclosing rock. These conditions are indicated in Fig. 7, reproduced from my report on the district.*

Furstenburg.—A similar example is quoted from Fournet by De la Beche.† The Wenzal vein at Furstenburg is nearly vertical and cuts down through many beds of gneiss, about 60

FIG. 7

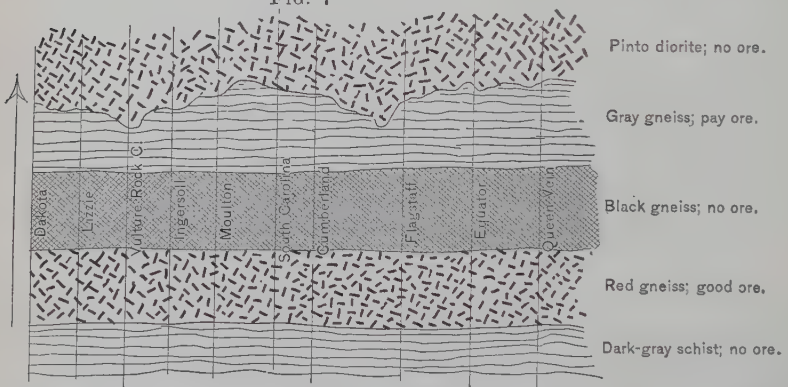


Diagram (Plan) Showing Rocks Traversed by the Neihart Veins, and Relation of Pay-Ore to Country-Rock. (The veins are indicated by simple parallel lines.)

ft. thick, that dip east. In the micaceous gneiss the vein is a nearly imperceptible string of clay. In argillaceous slates it suddenly becomes 12 to 18 in. thick, consisting of baryta, ruby-silver, large masses of antimonial silver, and argentiferous gray copper. In the hornblende-gneiss it continues, but the silver-ores are wanting and galena is the only ore. In the fourth series, of slightly micaceous beds of gneiss, the silver-ores are as abundant as in the argillaceous slates; but they gradually disappear in depth, being replaced by selenite and galena.

It will be noted that the Neihart veins present several contradictions to the rule observed in the Butte district. The ores

* "Geology of the Little Belt Mts., Mont.," *20th Ann. Rep. U. S. Geol. Surv.* 1900, Part III., p. 419.

† *Geological Observer*, Ed. of 1851, p. 781.

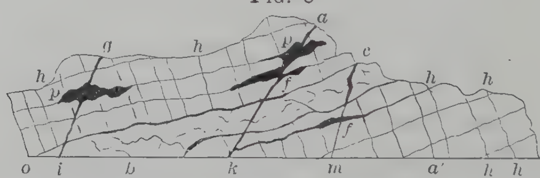
occur in the feldspathic rocks, carrying little ferro-magnesian minerals. The basic amphibolite and the diorite are both barren. It should be noticed also, in this connection, that the ore-depositing solutions were markedly different in the two cases. In the Neihart veins the gangue is mainly a mixture of carbonates of lime, iron and manganese. The ores are also markedly different, as they consist primarily of galena with sphalerite and pyrite, which is secondarily enriched in the upper parts of some veins. The solutions have been of such a character as to react with the feldspars rather than with the ferro-magnesian silicates.

Other Montana Localities.—In the silver-lead camp of Barker in the Little Belt Mts., near Neihart, as at the mines at Castle, Mont., and a score of other places where the ores occur in limestone, it is evident that different action has taken place. Here, as is so very commonly the case, the ore-bodies occur in limestone near the contact with igneous intrusions. The heat of the latter and the vapors of the cooling magma have altered these limestones to more or less coarse-grained marbles, if the limestones were pure, or to mixtures of garnet, epidote and other silicates, if the limestones were impure. The latter is the case at the Trout mine and other contact ore-bodies near Phillipsburg, Montana, where the Granite Mountain vein (of quite different and drier ore, without lead) occurs in the granite. In this case the gangue is largely silica; and it is probable that similar solutions circulating as a result of the heat supplied by the igneous intrusion, and, in part, at least, in fissures formed in rocks by the intrusion, formed one set of ores in the limestone and another in the granite.

Another instance of the difference of mineral contents in the same ore-deposit in different rocks is shown by the Elkhorn mine at the town of that name, Jefferson county, Montana. This deposit is peculiar in its structural relations, being similar to the well-known saddle-reefs of Australia in that it occurs in a saddle-shaped mass along the axis of a steeply pitching anticlinal fold. The rocks are sedimentary, of probable Cambrian age, and dip at steep angles toward the contact of a great mass of granite and other intrusive igneous rocks. The ore occurs at the contact between an altered shale and a massive crystalline limestone, and both rocks have been

changed by contact metamorphism. The bedding-plane is ore-bearing only where the general dip of the rocks is disturbed by flexures. In addition to the ore found along the contact, a number of very large ore-bodies have been found at some little distance in the dolomite, though always in the same structural position. The ore found along the altered shale-dolomite contact is essentially a "dry" quartzose milling-ore; that of the dolomite, mainly galena, with accessory sphalerite and pyrite. Both ores are connected by "pipes" and stringers, and both the field and the microscopic evidence show that they were formed by the same solutions and at the same time. There is no escape from the conclusion that the difference in the mineralogical character of the ores is the result of the different nature of the enclosing rock.

FIG. 8



Limestone Beds of Derbyshire, with Intercalated Beds of Igneous Rock (Toadstone) Traversed by Veins. (De la Beche, *Geol. Obs.*, p. 784.)

It would be tedious to enumerate all the familiar deposits in limestone. Those of Leadville, Colorado, and Eureka, Nevada, have been thoroughly studied and described. Tombstone, Arizona, presents quartzose veins filling fault-fissures, cutting slightly tilted sedimentary rocks, with the workable ore-bodies formed by replacement of limestone along bedding-planes, and presumably by the same solutions that filled the fissures.

Derbyshire.—The Derbyshire lead-mines of England are also well-known examples of veins carrying galena in limestone, and barren when in the intercalated intrusive trap-rocks (toadstone). Fig. 8, from De la Beche, illustrates the occurrence of galena in the limestones above and below an intrusive sheet in one of the Derbyshire mines. The leader or fissure traverses the "toadstone" as well as the lime-rock, but it is only in the limestone that galena occurs in the altered area. The channels or rakes (*g i*, *d k*, *c m*,) were fissures, through which solutions reach the pipes or ore-bunches *p p*, the bedding-plane deposits *f f*, and the joint deposits *h h*.

Contact-Deposits.

As Lindgren has remarked in discussing the formation of contact-deposits, a chemical reaction seems to take place between the substances leaving the magma and the carbonate of lime, causing the deposition of new minerals and the liberation of carbon dioxide. In the cases mentioned in this paper, the evidence shows that the veins were probably formed, not by true pneumatolitic action, but by hot circulating waters which were as truly a result of the igneous intrusion as the vapors and gases of pneumatolitic action. The escaping vapors and gases from the magma were, it is believed, taken up by circulating waters of either deep-seated or meteoric origin, so that the "mineralizing agents" which had taken up and formed the volatile compound of various metals, as supposed by Lindgren, passed into solution. Concerning the occurrence of this class of deposits in limestone, Mr. Emmons's description of the Greenwood ores is quite significant. He says: "The ore-bodies are cut by eruptive dikes that do not apparently disturb or exert any *metamorphic influence on the ore*, and yet are not at all mineralized themselves." At a number of localities seen by the writer, the veins, if traced into the granite or diorite, would be found to be barren of galena, and generally without value. On the other hand, at Marysville, Montana, the veins show no appreciable change in character in passing through the altered shales or hornstones into the granite. It should be noted, however, that the ores at this place are not lead-bearing. Moreover, I am told by Mr. G. H. Robinson, the former manager of the mine, that in the earlier workings the veins showed a marked tendency to be richer in approaching the granite (or rather diorite) contact, and were poor when they passed into the granite.

Thunder Bay Silver-Veins.—Mr. H. V. Winchell tells me that the Thunder Bay district of Canada affords excellent examples of vein-variation in different rocks. The basaltic caps and sills of that region overlie Animikie slates and argillites, resting in turn upon taconites and several hundred feet of cherts. These rocks rest upon the basal quartzite overlying the Archean complex. The silver-veins are often from 8 to 10 ft. wide in the slates, and carry native silver and argentite with small amounts of blende, galena and pyrite, in a gangue of quartz, barite, cal-

cite, fluorite, etc. They are wide and productive in the slates, but split up into narrow and barren seams in the overlying trap-rock, and are barren in the underlying cherts and Archean rocks. The Rabbit, Silver Mountain, Beaver and other mines have been noted producers.

Kemp* describes the Silver Islet mine as a fissure-vein carrying native silver, argentite, tetrahedrite, galena, blende and nickel and cobalt compounds in a calcite gangue. The vein is in flags and shales of the Animikie series (Algonkian) and cuts a large trap-dike (gabbro), *within which alone the vein is productive.*

Influence of Carbonaceous Matter on the Formation of Ore.

The well-known reducing action of carbon has long been an accepted explanation of the occurrence of ore-bodies in carbonaceous shales. The silver-veins of the Animikie slate are often cited as examples. The Australian veins, which carry rich gold-ores only where they cross "indicators," are a well-known instance, and the *Fahlbands* of Norway another. Rickard ascribes the Australian ore-bodies to the reducing action of the carbonaceous shales. All the descriptions show, however, that although these indicator-reefs are strata of carbonaceous shale, they are remarkable for the amount of pyrite they contain, while other shale-beds crossed by the veins are also carbonaceous, but not pyritic. In previously published papers I have called attention to the reducing action of pyrite on solutions carrying copper-salts; and believe that this mineral is the real precipitating agent in both the Australian and Norwegian ores cited. This view, based upon field-observations and laboratory experiments, in connection with the work of the U. S. Geological Survey, is strengthened by the experiments made under the direction of my friend, Mr. H. V. Winchell, geologist of the Anaconda Copper Co., who finds that the mine-waters of that company's properties, though strongly charged with cupric sulphate and ferric sulphate, also contain large amounts of carbonaceous matter from the old mine-timbers. It is evident that if the carbon were an active reducing agent, it would reduce the ferric iron to the ferrous condition. On the other hand, ex-

* *Ore-Deposits*, 3d ed., 1900, p. 283.

periments show that pyrite from the Butte veins left for several weeks in the natural mine-waters became coated with copper-glance (Cu_2S).

Dependence of Vein-Minerals on the Character of Wall-Rock, Due to Metasomatic Chemical Reactions.

The examples given show that a variation of mineral contents coincides with the change of country-rock in many places and in many kinds of veins. A study of the vein- and gangue-minerals and of the rock contiguous to the ore-bearing fissures is therefore essential to a complete understanding of the origin of ore-deposits. The rocks forming the vein-walls are commonly altered. Where no such alteration is observable, it will usually be found that the veins are the result of the filling of cavities, and are thus excluded from the category discussed in this paper. Nevertheless, some metasomatic alteration of the rock adjacent to the fissure is usually present; and it must be admitted that many veins show evidence both of the filling of open cavities and of deposition by replacement.

As already indicated, the coincident variation of mineral contents and wall-rock is due to metasomatic action, whereby there is a chemical interchange between the rock and the vein-producing solutions. The metasomatic process varies greatly because the solutions vary. Lindgren* has treated the subject fully, and has indicated the chemistry of the process, so that a detailed account of the reactions involved is unnecessary here. According to his clear demonstration, the alteration of the same kind of wall-rock shows that the vein-forming solutions have varied greatly in their chemical effect upon vein-contents, even where the veins are of metasomatic origin.

The most frequent process seems to be, in granitic rocks, a reaction between the ferromagnesian minerals, such as augite, hornblende, biotite, etc., and the vein-forming solutions, with the formation of pyrites and other sulphides. If later reconcentration occurs, bonanzas are formed by reaction of the pyrites on later solutions. This process I have treated quite fully in a monograph now in preparation on the Butte ore-deposits.

---

* "Metasomatic Processes in Fissure Veins," *Trans.*, xxx., 578.

In other cases, the feldspars are attacked, and the iron minerals of the rock are not *replaced*. Such a case is described by R. C. Hills;* and Rickard ascribes the silver-lead ores of Pontgibaud, France, to the replacement of the feldspars of granulite, as already quoted.

The attempt to tabulate the relation between vein-contents and country-rock has been made by various writers, and lately by Stretch. The latter author, in his very interesting essay,† has given 139 occurrences, and attempted to eliminate the personal equation of the observer. It is evident, however, that existing literature is not adequate for such work. Too often the rocks are wrongly named, or receive generic terms only. The words "granite" and "porphyry" have long been used in a textural sense by mining engineers, and by many geologists unfamiliar with petrographic distinctions; and, as is well known, shales, limestones and sandstones grade into one another. For the careful study of metasomatic replacement, which must be made to establish scientifically a relation between country-rock and vein-filling, finer distinctions must be made. The granitic rocks of some writers include gabbros, diorites, granite and aplite, with a wide range of mineral and chemical compositions. The most that can be attempted at present is to present the known facts of occurrence in deposits about which there can be no doubt, or which have been carefully studied. The facts here set forth show the advantages of geological examination of the district about a mine, especially of the area containing the vein. It is evident that it is important to ascertain the extent laterally and the probable extent vertically of the rock in which the ore occurs; and, if other rocks occur, what they are and what effect, if any, they will have on the vein-fissure and vein-filling. Such associations have long been recognized in a rough way by the miners, who say "that mineral will not live long in such a rock." The instances noted in the literature of ore-deposits are few, compared to those actually encountered in mining operations, where the character of the vein has changed in depth. Such change is, it is true, very often due to secondary alteration, with or with-

---

* *Proc. Colo. Sci. Soc.*, vol. i., p. 20.

† *Pocket-Book for Prospecting, Locating and Valuing Mines*, Sci. Pub. Co., N. Y., 1900.

out reconcentration and enrichment of material, but in many cases it is probably due to change of rock.

Conclusions.

From the evidence presented the following conclusions are drawn:

1. The structural characters of vein-fissures, such as course, width, etc., vary with the nature of the country-rock.

2. The mineral contents of veins formed wholly by the filling of open fissures are not affected by the nature of the vein-walls.

3. The mineral contents of ore-deposits formed by metasomatic replacement vary with the nature of the enclosing rock.

4. As metasomatic processes vary in character with the nature of the solutions, no invariable general relation can be established between certain rock-types and rich ore-deposits.

The Cyanide-Assay for Copper.

BY HARRY HUNTINGTON MILLER, NEW YORK CITY.

(Mexican Meeting, November, 1901.)

In spite of its recognized irregularities, the cyanide-assay for copper has always been popular among volumetric methods, being easy and rapid, and reasonably accurate when the solution tested contains nothing but pure copper and ammonium salts. In order to secure this condition, however, especially in operating on low-grade ores, tailings and slags of complex composition, it is the practice to precipitate the copper from the ore-solution,—usually by means of metallic zinc or aluminum. The copper thus precipitated in the metallic form must be dissolved again; and the separation is never, in practice, complete, since an appreciable amount of the copper remains behind in the first solution, and the second solution always contains some of the other metals of the gangue; so that the result is at best but partially satisfactory.

On the other hand, if this course is not pursued, but (as is

the practice in many laboratories) the first solution, with or without previous filtration, is treated with an excess of ammonia and the resulting precipitate of Fe, Al, etc., is filtered off, the difficulties in the way of an accurate assay are still greater. A portion of the copper remains behind in the precipitate, necessitating a second and sometimes a third solution and re-precipitation to secure a precipitate free from copper. Even with this additional manipulation (and consequent loss of time) the results obtained are incorrect. The amount of the standard KCN required to decolorize the solution is affected by varying temperature, varying amount of free and combined ammonia, and volume of solution. The presence of other metals also affects the process. Silver, zinc and nickel, if present, react with KCN like copper, while manganese retains copper in the precipitate to a greater extent than iron, besides obscuring the end-reaction.

Having had occasion recently to make a large number of determinations of very low-grade materials, where it was necessary to know the copper contents accurately to within one or two hundredths per cent., I have employed the cyanide-assay with complete success, notwithstanding the difficulties above cited. Careful attention to details and the introduction of a system of comparative standardization have resulted in a method which leaves little to be desired as regards speed of working, combined with a very fair degree of accuracy. The principles involved are: (1) the greatest possible uniformity in every stage of the assay; and (2) the adoption for each particular class of material of a value for the KCN solution obtained by standardizing in the presence of that material.

Details of Working.

The details of an assay or set of assays of material containing from 0.1 to 0.5 per cent. of copper are as follows: 10 grammes of the ore are weighed into a No. 4 porcelain casserole and digested on the hot plate until complete solution is effected. The acids used, degree of concentration, time of heating, etc., will depend on the nature of the ore; and each operator will determine these features for himself, bearing in mind, however, that in this, as well as in all subsequent operations, what is once adopted must be strictly adhered to in every

assay of the same class. When solution has been effected, the sides of the dish are rinsed down with a stream of hot water and the proper amount of dilute ammonia is added, the contents of the casserole being well stirred before and after the addition of the ammonia. The assay is then returned to the hot plate, heated moderately for five minutes, and then filtered hot through a 7-in. filter into a narrow beaker of 250 c.c. capacity. Nearly the entire contents of the dish can be poured out at once onto the filter, and the balance is sluiced out with a stream of cold water. The mass on the filter is washed twice with cold water, the jet being forced with the full power of the lungs, so as to stir up and wash the precipitate thoroughly with the minimum quantity of water. The liquid filters rapidly, and the clear blue filtrate, after two washings, should now be almost cold (not over 70° F.); and if the washing has been properly performed the bulk should not be over 180 c.c. If it be less than this, more water should be added. It is convenient to have a strip of white cardboard bearing the 180-c.c. mark for the size of beaker used. By standing this strip alongside of the beaker the volume of the solution can easily be measured.

The solution, if cool and of the proper volume, is now ready for assay. Place the beaker under the burette on a square of white filter paper. Run in the KCN solution rapidly, stirring vigorously meanwhile. As the color fades, proceed more slowly and cautiously, adding the standard solution in drops, instead of a continuous stream, as at first. If the ore-solution contains manganese, a precipitate will begin to form as the color fades from blue to violet. This precipitate, which appears in the form of a dirty bluish-green or brown discoloration, obscures the end-reaction, and must be removed by filtration before the finishing-point is reached.

Keep the attention fixed on the side of the beaker, near the bottom, looking down transversely through the cloudy solution. As long as a decided tint of violet can be seen on the mirror-like surface of the glass, the cautious addition of KCN can be continued, drop by drop. Stop before this color becomes too faint, and filter rapidly through a thin filter-paper. Washing is unnecessary, as the solution is now too close to the finishing-point for the trace of copper absorbed by the filter to affect the

result appreciably. The filtered solution, which should be very light blue or pale violet in tint, can now be easily brought to a delicate, hardly perceptible rose-pink, which should be the finishing-point for weak solutions. For solutions containing much copper, it is necessary to finish with a more decided pink, since it takes a little longer for the last color to fade from a solution which was rich in copper at the start. Where no manganese is present, refiltering will usually be unnecessary, the solution remaining clear to the finishing-point. A considerable excess of manganese may cause trouble in the assay, especially in the presence of ammonic chloride, as the precipitated hydroxide then forms very slowly, and keeps making its appearance as a milky discoloration in successive filtrates. This can be very largely prevented, however, by the presence of sufficient iron, as the iron precipitate seems to carry with it all but a trace of the manganese.

A little longer heating after addition of the ammonia also aids in securing a filtrate free from disturbing quantities of manganese.

Standardizing the Potassium Cyanide Solution.

From what has already been pointed out, it will be clear that the amount of KCN necessary to decolorize the solution does not give the true amount of copper present in the ore, when the latter contains other bases which interfere with the assay. When the acid solution is precipitated with excess of ammonia, Ag, Ni and Zn, if present in the ore, go into the solution, and react like copper with the KCN; while Fe, Mn and Al are precipitated as hydroxides. This precipitate invariably contains a small portion of the copper which, in the case of iron, is probably mechanically retained; but where manganese is present there is a further retention, possibly as a manganate.

Arsenic may also form an insoluble arsenate; and Cr also interferes.

In looking for a way to obviate these difficulties, I began by assuming that the amount of copper retained by these causes combined, varied directly as the ratio of the total copper to the disturbing elements present. Experiment proved this assumption to be a true one, at least to a very close approximation; and, this fact once established, the course of procedure became clear.

In standardizing the KCN solution for any particular ore or class of ores of the same composition, two portions of 10 grammes each are weighed out for separate assays. To one of them is added a weighed amount of pure copper, and the two are run through together, being treated in all respects like regular assays. The difference in the number of c.c. of KCN used in the two assays represents an amount equivalent to the weighed excess of copper taken, and from this the true value of the ore is readily ascertained. Operating on the same weight of identical gangues, this figure (with frequent checking) is used. For a different gangue, or a different weight of the same gangue, another test must be made; and whenever an accurate determination of a new ore is required, the assay is run in duplicate as above described.

If due attention be paid to the above details, I believe the cyanide-method will prove itself superior to the iodide volumetric method. The latter is certainly no quicker, and consumes much larger quantities of chemicals, besides being subject to many sources of error. The colorimetric assay, an improved application of which has been described by Mr. J. D. Audley Smith in a recent paper before this Institute,* is adapted to low-grade ores only, and for these does not seem to possess any advantages over the cyanide method, either in point of time or accuracy of results.

By effecting the solution in acid on a thick asbestos pad, heated by gas- or gasoline-burners, a number of assays can be run through at once, requiring little or no attention from the time they are placed on the fire until they are ready for the addition of ammonia. The "mixed acid" used is kept prepared in quantity, and so is the dilute ammonia. For measuring out the portions of acid and ammonia for each assay, the most convenient vessel is a graduated cylinder of 100 c.c. capacity, with a foot.

The same method can be applied with equal success to richer ores, as well as to concentrates and mattes. For low-grade ores, containing not over 1 per cent. of copper, the KCN solution should not be stronger than 1 c.c. = 0.005 grammes of copper. For richer material, a solution of twice this strength can be used to advantage.

---

* *Trans.*, xxx., 851.

The Delamar and the Horn-Silver Mines: Two Types of Ore-Deposits in the Deserts of Nevada and Utah.*

BY S. F. EMMONS, WASHINGTON, D. C.

(Richmond Meeting, February, 1901.)

THE Delamar and Horn-Silver mines represent two important types of Basin Range deposits. Both are situated in a region which possesses to an extreme degree the characteristics of a desert, and show the effects of an arid climate upon the metallic minerals in ore-deposits—especially upon their secondary enrichment. At the same time, each presents certain interesting structural peculiarities. It is these facts that form my excuse for giving the dignity of a paper in the *Transactions* to my necessarily incomplete notes, made during a week's side-trip from Salt Lake City in October, 1900.

I. THE DELAMAR MINE.

Topography.

This mine is situated upon the western slope of the Meadow Valley mountains, about 70 miles by road from the present end of the railroad-track, which is at Uvada, on the Utah-Nevada boundary. This boundary-line marks fairly well a certain change in type of scenery from western Utah to eastern Nevada,—from a region in which the desert valleys predominate over the mountain ranges to one in which they are in about equal proportion. The railroad from Salt Lake City runs somewhat W. of S., for the most part along the bottom of the ancient Lake Bonneville. The latter part of its present course follows the axis of the southern arm or bay of that lake, now known as the Escalante desert. Along this bay, its line is a mathematically straight one, with no perceptible change of level for two "tangents" of more than 30 miles each, varying but a few degrees in direction. In the four or five hours re-

* Published with the consent of the Director of the United States Geological Survey.

quired to traverse this distance, there is little to relieve the monotony of the landscape; the bounding mountain-ranges being too far away (15 to 20 miles on either side) to permit much study of their forms or structure.

From Uvada, the wagon-road winds a little N. of W. to a divide at the southern end of the Needle Mts., an irregular group of volcanic hills covered with an open growth of piñon and juniper, from which one looks down into a valley typical of southeastern Nevada, the Meadow Valley, which drains southward through the Virgen river into the mighty Colorado, and thus into the ocean. At this point the valley, 15 to 20 miles wide, is partially enclosed and filled by Tertiary and Pleistocene beds, the latter having a beautifully regular slope from the foot of the bounding ranges to the fairly wide alluvial bottom. Both series of beds are dissected and unusually well exposed by the erosion of a number of tributary ravines, which extend for some miles back from this central bottom. To the traveler, looking down on this valley from the divide, over the gently sloping Quaternary spurs, a small spot of brilliant green about the size of a pin-head is pointed out as the town of Panaca, said to be 12 miles distant, though it looks scarcely more than 2 or 3. When reached, after a two hours' drive, it is found to be a considerable settlement of Mormon farmers, with double brooks of clear water flowing through all the rectangularly arranged streets, and an abundant grove of soft-wood trees surrounding every house. In the midst of the town rise little castellated buttes, 70 to 100 ft. high, formed of beds of the rhyolitic tufa, of which the Tertiary beds here consist, and the dazzling whiteness of which is broken only by thin horizontal bands of dark green chert. On the further side of the bottom is the abandoned town of Bullionville, once the place of reduction of the ores of Pioche.

Meadow Valley, as has been remarked, is one of the typical valleys of southeastern Nevada. The whole State—indeed, in a measure, the whole Great Basin area—is ribbed by a series of more or less regular and continuous N. and S. mountain ranges, relics of an older and now partially buried topography. The northern part of the State, like the Great Basin of Utah, had no exterior drainage, and was once occupied by Lake Lahontan, the companion of Lake Bonneville. In this area the

deepest portions of the present valleys are occupied either by actual lakes, or by *playas* (mud-lakes). In the southern portion, however, many of the valleys belong to the drainage-system of the Colorado, though few of them probably have continuous streams, except possibly in times of unusual flood. Of such is Meadow Valley, sometimes called the Meadow Valley wash.

Immediately north of Panaca and Bullionville, and separating the latter from Pioche, a ridge of upturned Paleozoic sediments crosses the valley nearly at right angles. The waters that fertilize Panaca and its surrounding farms gush out of the Tertiary beds near where they abut against this cross-ridge, and close to the valley-bottom. For many miles they flow in a considerable stream on the surface, and then disappear; then follows a stretch of dry valley, and again another spring, or set of springs, starts a new stream. Above the transverse ridge just mentioned, through which the present drainage runs in a narrow winding gorge, there are several open valleys occupying the same general line of depression as Meadow Valley. In like manner, for 12 to 15 miles below Panaca, there are broad stretches of meadow-land on the alluvial bottom; then the valley shrinks again into a narrow cañon, in places 2000 ft. deep, which continues, perhaps, 20 miles. It is these intermittent valley-openings, and alternate watered and dry stretches, that characterize this and other valleys of its type.

The eastern boundary of Meadow Valley is a steep, narrow N. and S. ridge, which rises to a height of nearly 10,000 ft. opposite Pioche, and is mainly made up of beds of limestone and quartzite of Cambrian or later age. About opposite Panaca a low gap in this range affords a route for the main travel westward, having the advantage of a good spring, widely known as Bennett's spring, and situated just E. of the summit, near the upper edge of the valley Tertiary beds.

South of Bennett's spring, the Highland range, losing the character of a sharply defined single ridge which it had to the north, widens into an irregular series of hills of moderate elevation, known as the Meadow Valley range. This is largely made up of eruptive rocks, which have broken through, displaced and in places buried the sedimentary rocks, so that fairly continuous exposures of the latter are found only along the western flanks.

FIG. 1.

Delamar Mine and Mill. (The dumps on the left are mill-tailings. The first large dump to the right of the mill is that of No. 10 tunnel.)

Fig. 2.

Delamar Mine and Town from SW. (April Fool Mine up gulch to right; tunnel dump and [illegible] to left.)

The valley W. of the Highland range belongs to a type still more common in Nevada—that of the enclosed valley, ending at its lowest point in a *playa* or mud-flat. This one is of so little industrial importance that it has no special name, but comes under the general title of "desert valley." Beyond it on the west is the fine single ridge of the Pahranagat range; and beyond that again is another valley of the Meadow Valley type, dotted with Mormon farming-settlements, and deriving water for irrigation not, as in the more eastern regions, directly from the melting of the snows in the high mountains, but from springs gushing out near the valley-level. The natural drainage of the Pahranagat valley to the southward bends eastward around the southern end of the "desert valley" and joins that of the Meadow Valley before reaching the Rio Virgen.

The works of the Delamar mine, and the little town of the same name, occupied by its employees and those of the adjoining April Fool mine, are situated on the western slopes of the Meadow Valley range about 30 miles S. of Bennett's spring and 50 miles from Pioche. (See Figs. 1 and 2.) They are built upon the flat part of a spur of the mountains, between two ravines, and are a little more than 1000 ft. above the edge of the valley, where the rocky ribs of the range disappear beneath the slopes of Pleistocene gravel. From this point one has a fine view to the W. and S. over the "desert valley," which exhibits very gentle slopes of Pleistocene gravels, covered with sage-brush, excepting a narrow, dry "wash," which forms its lowest part and lies a little W. of the center. This wash can be traced by the eye as running southward, like a dry river, to the *playa* in which it ends—a brilliant white mud-lake almost entirely enclosed by dark hills of volcanic rock. An idea of the depth of the Pleistocene gravel is given by the fact that, 7 miles out from the foot-hills and more than 1200 ft. below the Delamar mill, a well sunk to the depth of 900 ft. was apparently all the way in this gravel, and as dry at the bottom as at the top.

General Geology.

The general form of the mountain slopes, on which the Delamar mine is situated, is shown in the accompanying sketch (Fig. 3), in which the relative position of the different ravines and mine-works is taken from a local survey by Mr. F. A.

Swindler, the present mine-manager, and the topographic forms are roughly sketched in from memory.

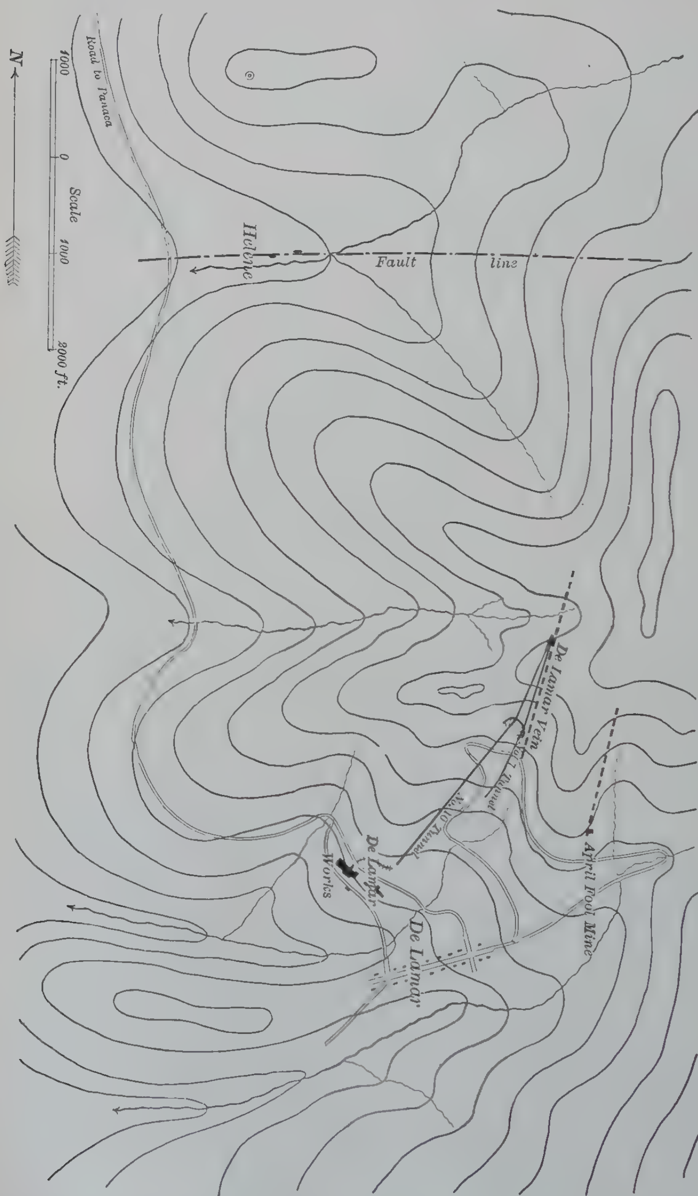


FIG. 3.

Delamar and Vicinity.

The geological structure of this region is extremely simple. The mountain slopes at the mine are made up of a heavy series

of quartzite beds, striking N. 30° to 40° E. and dipping 23° SE., which are traversed by a few narrow dikes of porphyry. No other beds than quartzite are seen in the immediate vicinity; but they are said to be overlain, on the hills to the eastward, by limestone strata. The more eastern portion of the Meadow Valley range, opposite here, while largely made up of eruptive rocks, shows a few outcrops of quartzite.

Along the western slopes, as the beds are followed northward, the strike apparently suffers a gradual change to the N. and then to the W. of N., the dip still continuing to the E. A little more than a mile N. of Delamar, a broader and deeper ravine, in which the now extinct mining camp of Helene was situated, is apparently the *locus* of an E.–W. fault, with a considerable downthrow to the N.; for on the spur beyond the ravine, on which the Magnolia mine is situated, the quartzite beds strike NW., and are immediately overlain by a series of dark green shales capped with limestones. The local thinning and thickening of the shales seems to indicate a probable unconformity, due to erosion, between the quartzite and limestone. About a half-mile further N., near the Monkey-Wrench claim, the beds have bent around so as to strike W. and stand nearly vertical, dipping N. Here a considerable intrusion of white quartz-porphyry has spread out in the green shale horizon between the quartzite and limestone. The general structure of the region thus appears to be that of the truncated end of a broad E.–W. anticline which pitches E. and has its steep side to the N.

The hills E. of the works of the Delamar mine rise in a rugged and fairly steep slope, at angles of about 20° to 30°. The main outcrop, where the rich mineral was originally discovered, is about 1000 ft. above the mill, and is now occupied by a considerable open-cut, mainly caused by the caving of the upper stopes in the large ore-chimney. The mine has been opened by a series of tunnels, successively longer and deeper as the ore-bodies have been worked downwards, until now the main working-tunnel on the No. 10 level, which opens at the level of the upper part of the mill, is 757 ft. below the uppermost or No. 1 tunnel, and has an extreme length of 3100 ft. It runs practically with the strike of the quartzite beds, diverging a little to the N. at 2100 ft. from the mouth, to follow the

so-called vein. The mine has been opened for six levels, or about 600 ft. below this tunnel, but the lower workings were inaccessible at the time of my visit. The general disposition of the mine-openings is shown in Fig. 1, tunnels No. 10 and No. 7, and the open cut above, being in line on the left side of the photograph.

Vein-Structure.

The so-called vein is a strong fracture, striking about N. 30° E., or nearly with the quartzite beds, but dipping 70° to 80° NW., or nearly at right-angles to the stratification. I say "so-called" vein, because it has neither vein-filling nor is the main fracture itself mineralized to any considerable extent. The pay-ore is found in zones or shoots of crushed quartzite adjoining this fracture. They are not, however, continuous along the fracture.

Several other fracture-planes in the quartzite have been developed by various underground explorations, none of which have been found to carry workable ore-bodies except that in the adjoining April Fool mine, which I did not have time to examine. I shall confine my remarks, therefore, to the conditions of the Delamar mine, which are not quite as simple as might be inferred from the above statement, but are complicated by the existence of several porphyry dikes. Two of these dikes, known as No. 1 and No. 2, each 30 to 40 ft. thick, strike in a general E.–W. direction, or nearly normal to the main fracture-plane; but their courses are rather irregular and not strictly parallel. The rock of these dikes is a normal granite porphyry, or quartz-porphyry, as it has been more generally designated hitherto.

The third dike, known to the miners sometimes as the "black" dike and sometimes as the "gouge," is only from 6 to 10 ft. wide. From an examination of its least altered portions it appears to belong to the basic rock type known as lamprophyres or minettes, and its direction coincides with that of the main fracture-plane. Indeed, this dike has apparently determined the course of that plane; for, as far as could be seen, the latter is always included within it. But there has been also a good deal of fracturing at different points in the adjoining quartzite, parallel with the dike; and this collateral fracturing has produced the zones of crushed quartzite in which the prin-

cipal mineral deposition has taken place. All the dikes were intruded previous to mineralization and fracturing.

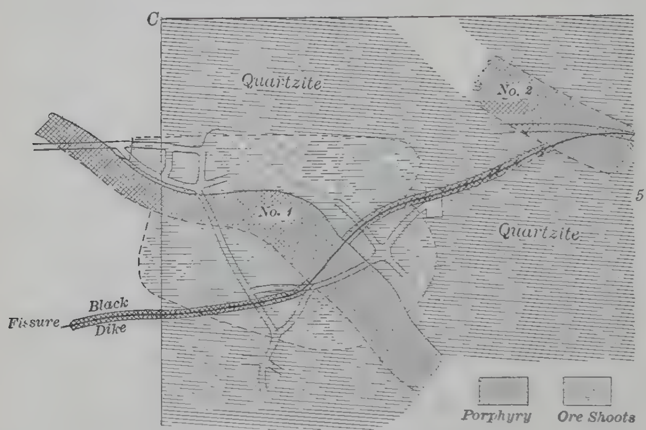
It had been assumed previous to my visit that the two larger dikes, Nos. 1 and 2, were more recent than the "black" dike, since on some of the levels they seem to have displaced it. My own examination, however, led me to think that the "black" dike had been injected later than the other two, although, by reason of the fact that where they were visible in the mine both were so decomposed as to present little more than an amorphous clay mass, in which no original minerals could be distinguished, I could not be certain of this conclusion. In any event, the fracture was distinctly later than either, and could be traced across the two larger dikes in the line which the "black" dike would normally have followed. Moreover, along this line a slight stain of manganese oxide was generally observed, which seems to be characteristic of the "black" dike and perhaps gives it that name. Finally, the present forms of the dikes, as shown by tracings of both horizontal and vertical planes, give evidence of considerable warping near the plane of intersection; and, while the "black" dike is slightly warped also, its general course seems much straighter than that of the other two. My inference is that, while the later warping was produced by the same forces that shattered the quartzite and caused the main fracturing, some of the warping in the larger dikes must have been previous to this, and possibly the result of the forces that induced the intrusion of the "black" dike.

Figures 4, 5 and 6 show the distribution of dikes and main ore-bodies on the 5th, 6th and 7th levels respectively, the latter being the one that has been most extensively worked, and consequently most exhaustively examined.* The main ore-body occurs at the intersection of the "black" dike and the No. 1 and No. 2 dikes, and, as shown in the plans, is divided by the

* The outlines of the porphyry dikes in these figures are constructed from actual intersections in the drifts of the mines. The outlines of the ore-shoots, on the other hand, are necessarily arbitrary, since the ore grades off into slightly impregnated quartzite, and there is actually no defined limit between pay-ore and country-rock. The point C and the lines running from it in each plan are in the same vertical planes, and thus show the pitch of the dikes and ore-shoots. The thorough and systematic manner in which the mine surveys are kept up at this mine rendered it possible to obtain in a few days a clear conception of the underground structure, which, without them, might have involved the labor of many weeks.

intersection of the No. 1 and the "black" porphyry dike into four parts, the dikes themselves being barren of mineral. These

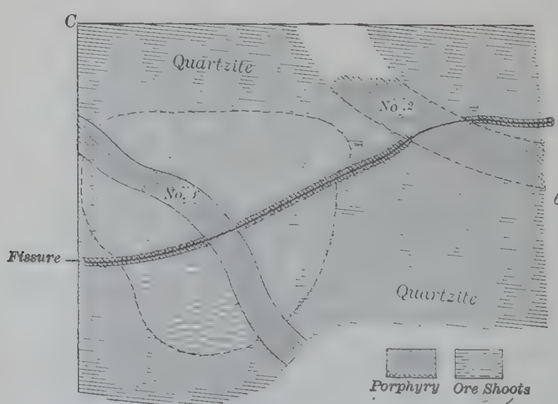
FIG. 4.



Fifth Level of Delamar Mine.

are called, respectively, the No. 1 shoot; the Northeast, the East and the Southeast shoots; the No. 1 being on the NW. side of the intersection, and that which is first reached by the

FIG. 5.

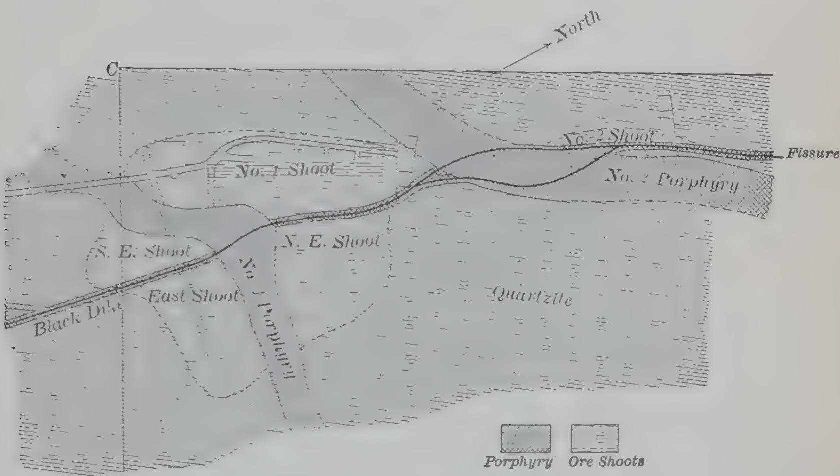


Sixth Level of Delamar Mine.

tunnel. The other shoots are smaller and have been developed since the first one was opened. No. 2 shoot is beyond the No. 2 porphyry-dike and on the hanging-wall side of the "black"

dike. No. 3 shoot is along the hanging-wall of the ore-body still further NE. As already remarked, there is no vein-filling: the ore consists simply of crushed quartzite, in which, as a general rule, no metallic minerals are visible. The crushing has evidently been more intense at the intersections of the porphyry-dikes. As is shown in Fig. 4, the No. 1 dike is bent and apparently widened out at the point of intersection with the "black" dike, whereas, as shown in the tracing on the other levels, the "black" dike is also bent, so as to produce an apparent displacement at this intersection.

FIG. 6.



Seventh Level of Delamar Mine.

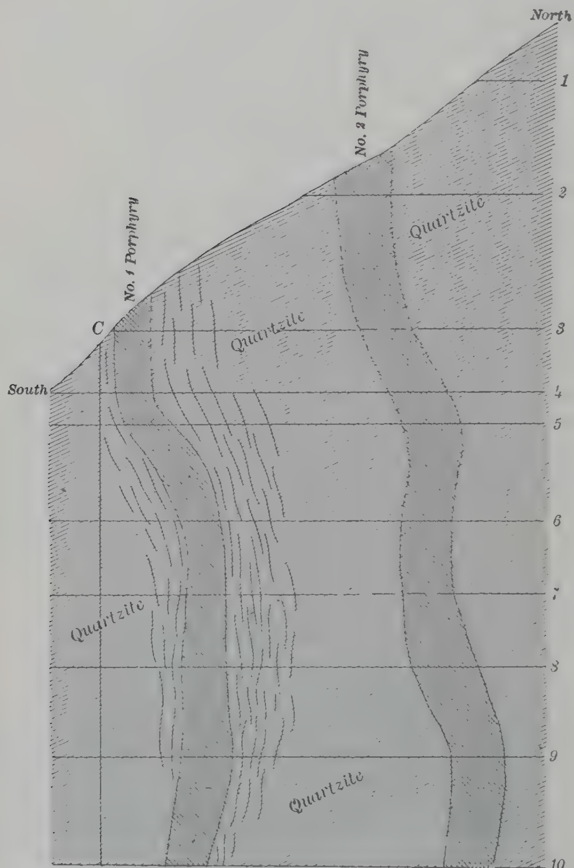
In Fig. 7, which shows a vertical section of the dikes, constructed from data afforded by the intersections at the different levels of the mines, both dikes show some warping on the dip as well as on the strike.

Character of the Ore.

At first glance, the Delamar ore appears like any piece of slightly oxidized quartzite that one might pick up on the hills. It is of the oxidized ore that one naturally speaks, since oxidization extends down to, or even below, the 10th level, and the sulphide-ore that has been found below that level is too low in grade to pay for mining. Closer examination of a typical speci-

men of this oxidized ore shows, however, that the granular structure of the original quartzite has more or less completely disappeared and that the mass has a certain resemblance to jasperoid, or the siliceous replacement of limestone, which resemblance is heightened by the frequent irregular and gen-

FIG. 7.



N.–S. Vertical Section through Delamar Mine.

erally angular cavities such as are ordinarily characteristic of the latter. One can also distinguish that the quartzite has been shattered into angular fragments and re-cemented by quartz.

The microscopic examination of a specimen of so-called sulphide-ore, which my colleague, Mr. Lindgren, was kind enough to make for me, shows that while portions of the origi-

nal quartzite remain and show an entirely normal structure, the greater part has been altered into a finer aggregate of interlocking structures through the corrosion of the original quartz and its re-precipitation in more or less crystalline form. Some places are filled with coarser quartz-grains, which apparently have been deposited in open cavities—probably the interstitial spaces between broken fragments. Besides the quartz there is no other mineral present except scattered, well-developed crystals of pyrite. Mr. Lindgren remarks: "The recrystallization of the quartzite, which has progressed so far as to leave only smaller masses of the original rock unattacked, is certainly a remarkable phenomenon; and I know of no exactly similar occurrence."

In another specimen of the unaltered ore a white metallic mineral is visible in considerable amount, which is some form of telluride, too finely divided for specific determination; and a slight greenish copper-stain is visible on the outside of the specimen. Microscopic examination of this specimen shows some pyrite and chalcopyrite, associated with the telluride, and none of the original quartzite remaining.

The pyrite is in such minute grains as scarcely to be distinguishable by the unaided eye. So little of the unaltered ore was seen in the mine that it was impossible to form any definite opinion, whether the telluride was probably the prevailing original form in which the gold occurred. In the unoxidized ore the slight reddish stain, though in part undoubtedly iron oxide, might have proceeded in part also from the oxidation of the telluride. No native gold was detected either macroscopically or under the microscope. It can only be asserted, therefore, that a part, at least, of the gold was deposited as telluride.

The remarkable feature about the action of the ore-bearing solutions, as determined by these examinations, is that they first dissolved out, and then re-precipitated silica, without, however, completely filling the open spaces. The fact that the main fracture and the enclosing porphyry-dike are practically barren, while the ore was deposited in the adjoining shattered portions of the quartzite, is also interesting, though not unprecedented. Mr. Lindgren informs me that he has observed similar occurrences where a narrow lamprophyre dike had cut dikes of more acid porphyry and fracturing had taken place, which

followed the lamprophyre dike; but the subsequent mineralization was in the adjoining country-rock and not in the dike itself.

Distribution of Values.

A phenomenon more important from the economic point of view than either of the above generalizations is the peculiar distribution of values in the mine. The bullion is what is generally known as *doré*. It contains in value 300 of gold to 600 of silver and 100 of base metals—probably, in the main, copper. The tenor in gold increased from the surface downward to about the 7th level, though the values, as is generally the case, were very unevenly distributed. Some lots of ore received at the Taylor and Brunton sampling-works at Salt Lake City ran as high as 30 oz. per ton in gold. The owners say that the values in the richer part of the mine averaged from $30 to $70 per ton. At the 10th level this had decreased to $4 or $5 per ton, and in the lower levels it is said to have fallen to $1 and $2.

The geological conditions have remained constant from the upper levels to the lowest yet opened. The shattered zones of quartzite and the general distribution of the mineralized area are said to be practically the same in depth as they were above, but the values are wanting. The natural inference would seem at first sight to be that this is due to a secondary alteration by which, as the surface has been eroded off, the gold has been leached downwards,—probably by the agency of ferric sulphate resulting from a decomposition of the pyrite,—and re-deposited below. There is no water-level in the mine, since it is as dry in the bottom as it is in the upper levels.* There is also very little precipitation under present climatic conditions, so that, according to the testimony of the miners, the mine is never wet. This is, however, a common condition of mines in the arid region, and yet there is universal evidence of a secondary en-

* This extreme dryness is a remarkable feature of the mine. The walls are covered with an impalpable flour-like material, which is a finely powered silica, resulting from the fact that the ore in the upper levels is sent down through chutes often to distances of several hundred feet to the 10th, or working-level, and in the neighborhood of the main chute the drift is ankle-deep in this fine flour-like silica. The effect upon the miners is, according to popular testimony, deleterious. Lung diseases are said to be very common among them.

richment that must have proceeded from the surface downwards. This enrichment may date back to a geological period when, under different climatic conditions, there was a larger precipitation. There is definite geological evidence of one or more such periods in comparatively recent geological time, the best marked of which was the Bonneville period, when the lake of that name was at its highest stage.

History and Development.

The development of this mine presents so remarkable an instance of the triumph of individual energy and good management over apparently almost insurmountable natural obstacles, as to warrant a brief sketch of its history. The various mining claims which constitute the present property came into the hands of the present owner, Captain De Lamar, in 1893, after he had satisfied himself of their value by a careful personal sampling of the ore then exposed in the various openings. The original purchase-price was $150,000; but it is said that $600,000 was expended by Captain De Lamar before the property became productive.*

The first difficulty to be overcome was the want of water, the very few springs in the neighborhood being incapable of furnishing a sufficient supply, even for domestic uses. The first attempt to remedy this want, through the sinking of an artesian well in the "desert valley," was a failure, the well being as dry at 900 ft. as when it was started. Recourse was then had to the Meadow Valley wash on the western side of the range, where water existed practically at the surface, and this adventure was successful. From a well only 20 ft. deep in the soft valley bed the present pumping-plant raises the water, which is forced through a $3\frac{1}{2}$ in. pipe, and by three successive pumping-stations is carried to the summit of the range at a low divide somewhat south of Delamar, the total vertical lift being 1500 ft. Thence it runs by gravity to the town and the tanks on the hill-slope above the mills. The present consumption is about 40 gallons per minute, of which 15 gallons is used in the cyanide-mill, and the balance for domestic, steam and other purposes. The

* The gross yield since that time is given in round numbers as nine million dollars in gold and silver.

amount thus pumped is said to cause no perceptible lowering of the supply in the well.

For extracting the bullion from the ore a chlorination-plant was first built, which was provided with a Pearce turret-furnace for preliminary roasting. To bring in the heavier parts of the machinery, teams of as many as fifty horses had to be used at times. The chlorination process, however, was finally abandoned, it being said that much of the values, especially of the silver, was lost in the roasting.

A cyanide-plant was then established, small at first but increased by successive additions, until the mill as it stands to-day (see Fig. 1) has a tank capacity of 3250 tons and treats, on an average, about 300 tons of ore per day.

Quite a town has sprung up around the mines, occupied mainly by employees of the Delamar mine, and of the adjoining, but much smaller, April Fool mine (see Fig. 2).

The Delamar pay-roll comprises at present, exclusive of the staff, about 250 men, of whom about 150 are employed in the mine, 65 in the mill and others in various capacities. The staff includes an able surgeon, as both mining and milling are somewhat trying on the health of the operators. All are comfortably housed, the married men having well-built frame-houses, furnished by the company. Stone bunk-houses are provided for the miners, the room-rent at $2.00 per month. Most of the men, however, prefer inferior quarters at a higher price in the town. In this dry and windy country extraordinary precautions have to be taken against fire, in spite of which the town has been burned down more than once.

The mill-plant has one 13 by 30 in. and two 10 by 16 in. Jumbo Blake crushers, the latter of which work alternately. From these the ore goes to the Griffin mills, of which there are thirteen, with a capacity of 25 tons per 24 hours each; there it is ground to a fine powder, and thence sent to the tanks.

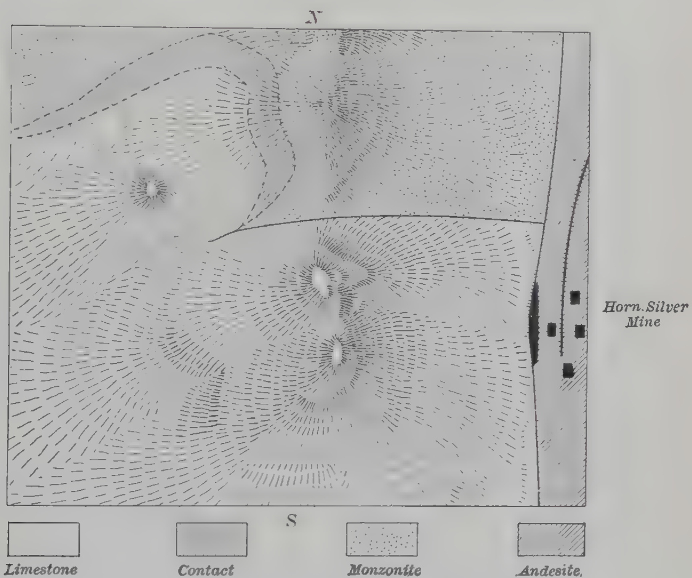
The cyanide-process employed here is rather unusual, in that the precipitation is by zinc-dust instead of zinc-shavings. The patent-rights for this process belong to Captain De Lamar. It has apparently proved very successful, the report being that the tailings which have gone onto the dumps during the last 21 months have carried an average value of less than $1.00 per

ton, although the earlier tailings were richer. Of the whole 400,000 tons on the dump, the greater part will run about $2.50 per ton.

II. The Horn-Silver Mine.

The Horn-Silver mine lies at the eastern foot of the southern end of the San Francisco mountains, locally known as the Grampian hills, about 17 miles west of Milford Junction, Utah, and 1400 feet higher. As contrasted with the region around the

Fig. 8.



The Grampian Hills.

Delamar mine the geological structure is here relatively complicated. The mass of the southern end of the Grampian hills is made up of dolomitic limestones, the exact age of which has not yet been determined. A low pass in these hills, opposite Frisco, a few miles N. of the southern point of the mountains, is the *locus* of an E.–W. fault which brings up a body of crystalline rock, locally known as syenite, but more strictly a monzonite, abutting against the limestone. (See Fig. 8.)* This

* This is simply a sketch, made totally without measurements and largely from memory, designed to show the relative position of the respective rock-masses with reference to the Horn-Silver fissure.

the country-rock from 200 to 300 ft. E. of the outcrop, and was considered safe from the influence of the caving ground. But, as will be shown later, the true hanging-wall fissure crosses it at a depth of about 900 ft. The surface caving long ago rendered the shaft useless, and the shaft-house is not only out of plumb but slightly skewed in azimuth.

Earlier Developments.

It is impossible to obtain complete data as to the earlier developments of this remarkable mine; but from such published information* as is accessible the following imperfect sketch has been compiled:

The mine has been essentially a lead-mine. Croppings of galena are said to have been seen throughout the length of the claim; yet the ore is oxidized to the greatest depths thus far explored, and the bulk of the lead seems to occur in the form of sulphate or anglesite; hence the galena may be assumed to have been residual kernels that had escaped oxidation.

The main ore-body is said to have had a width at the point of discovery of from 40 to 60 ft., while the stopes on the 1st, 2d and 3d levels show continuous openings on this ore-body up to 300 ft. in length. The axis of the body runs N. 35° W., but that of the fault-zone, as a whole, is N.–S. magnetic.

Again, it is said that "the walls of this great ore-chimney have come close together twice in a vertical depth of 1200 ft., dividing it into three almost distinct ore-bodies."

Furthermore, certain descriptions of material seen in hanging-wall cross-cuts show that what was then regarded as hanging-country was in part, at any rate, fault-material. Now, observations in the lower levels show that the bounding-planes of the great fault-zone, especially the hanging-wall, have a comparatively regular direction in dip as well as in strike; hence it seems probable that this great ore-body was simply a limited portion of the fault-zone, in which mineralization had been concentrated by some cause not determinable at the present day, but presumably dependent upon the minor fracturing

---

* Rpt. W. A. Hooker, quoted by D. B. Huntley, *Tenth Census*, vol. xiii., p. 464; O. J. Hollister, *Trans.*, xvi., 7; also the Horn-Silver Company's *Reports* for 1881 and 1882.

that has gone on within the general zone included between the solid limestone foot-wall and the hanging-wall andesite.

As described by Mr. Hooker, the ore was roughly divided into two classes: *milling-ore*, which was free from lead, and *smelting-ore*. The former included (*a*) *sparry ore*, which was the richest in the mine, consisting mainly of barite with horn- and ruby-silver, and carrying an average of 70 to 200 oz. of silver per ton: and (*b*) *mottled ore*, which was very impure and siliceous, and sometimes carried considerable lead. The smelting-ore consisted largely of sulphates with some carbonates and oxides of lead, and was generally rather soft and clayey. It carried from 30 to 60 per cent. of lead and 30 to 75 oz. of silver per ton. An analysis of a sample of this ore gave: lead, 50; arsenic, 0.93; antimony, 0.26; and silica, 15 per cent. No zinc or copper was found, though the former was especially looked for. The smelting-ore constituted the greater bulk of the ore mined.

On the 4th and 5th level another variety of ore was distinguished, which replaced the sparry ore on the E. or hanging-wall side of the ore-body, when the latter had disappeared. It was called *leaching-ore*, and carried nearly 50 per cent. of silica, with more arsenic and antimony and a little zinc. There seemed to have been some kind of a definite boundary between this and the smelting-ore; possibly a former fracture-plane. No copper is noted in any of the analyses given.

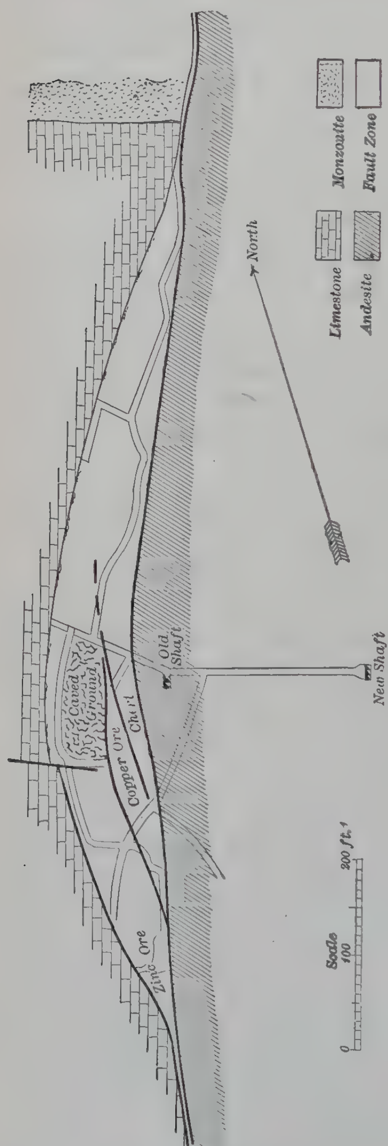
Later Developments.

My own observations were confined to an examination of the 7th level, and a hasty glance at the 10th and 11th levels, and, by reason of the want of underground maps, were much less satisfactory than could have been desired. There are, therefore, large gaps for which no data whatever are available. On the plan, Fig. 9, and the vertical section, Fig. 10, the positions of the foot- and hanging-walls have been determined with a fair degree of accuracy; but the outlines of ore-bodies within the fault-zone are only roughly sketched.

The hanging-wall country, through which the new shaft is sunk and cross-cut drifts are run to the fault-zone at each level, is more or less decomposed, and is traversed by numerous fracture-planes, which have a general parallelism in strike with

the Horn-Silver fissure. These are often nearly as prominent planes as that of the hanging-wall itself, but the latter marks the passage from comparatively solid rock to the distinctly brecciated fault-material, and its plane is often occupied by a thin seam of fibrous gypsum.

FIG. 9.



The 700-ft. Level, Horn-Silver Mine.

The fault-material, or rock-mass comprised between this hanging-wall fissure and the limestone foot-wall, is of a varied nature. On the hanging-wall side, especially N. of the shafts, it is recognizable as altered igneous rock; near the foot-wall, on the other hand, there is much more or less altered limestone; but the greater part of the mass is so changed that its original character cannot be determined. Thus, W. of the old shaft on the 7th level and adjoining the caved ground (see Fig. 9) is a body of much shattered hornstone-like chert (called by the miners rhyolite) which is here only about 15 ft. thick, but increases to more than 100 ft. in the lower levels.

Only portions of the fault-zone are mineralized; but it was not possible to determine the outlines of the ore, first, because of the great cave in the main ore-body, extending from the surface down to the 7th level, which the

drifts run by the present management have been obliged to avoid; and, secondly, because the pay-ore grades off into material which, though mineralized, is too low in grade to be worked at present, and is not recognized as ore. The great ore-shoot, or main ore-body, followed from the surface downwards, appears to have had a general pitch S. and E., and to have become very much attenuated, both in size and value, in the lower levels below the 7th. It was probably the variations in this body that were referred to when it was said that "the walls have come together twice in a vertical depth of 1200 ft."

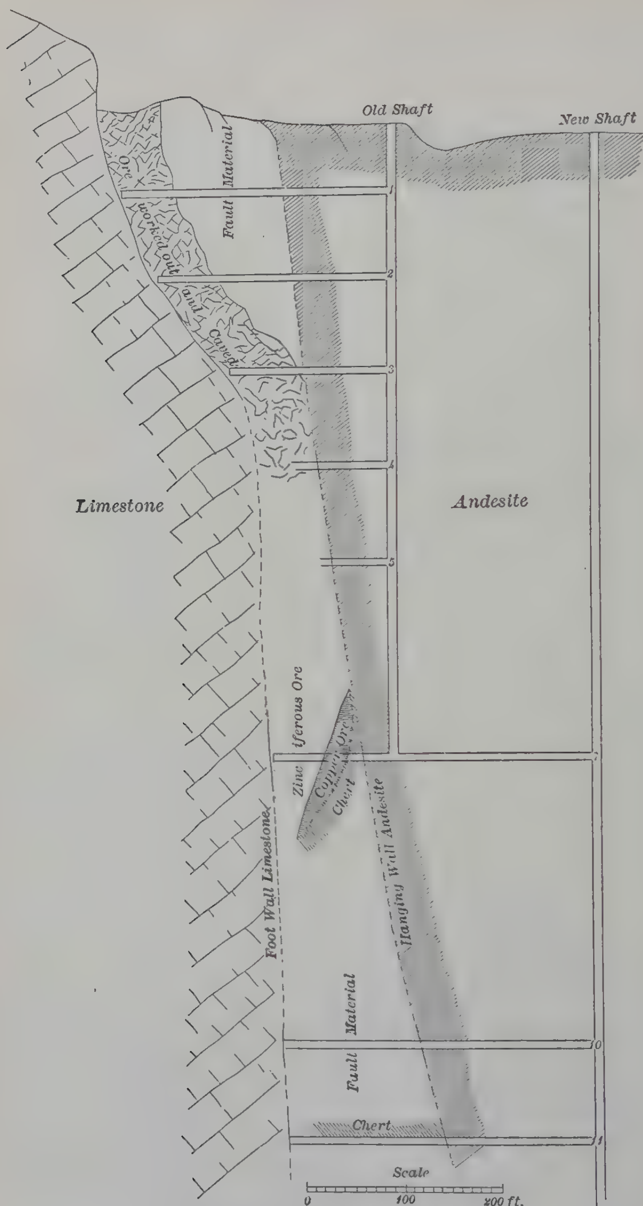
The point of greatest interest developed by my visit was the distribution of the metals within the general mineralized zone. As observed above, neither copper nor zinc were found in the upper part of the ore-body. Zinc came in in small amounts scattered through the ore in the 5th level, and increased downwards until at the 7th level there is an enormous amount of zinciferous ore in the southern end of the fault-zone. The zinc is largely in the form of carbonate or silicate; some lead and a little barite are associated with it. The average yield of a lot of 500 tons of this ore sent to the sampling-works near Salt Lake City was:

	Per cent.
Zinc,	40.00
Lead,	8.00
Iron,	4.00
Silica,	20.00
Sulphur,	28.00

and 6 oz. of silver per ton. The present manager estimates that he has 300,000 tons of zinc-ore in sight. It is said to extend nearly down to the 10th level.

Copper is said to have been seen first at a depth of 650 ft.; and it extends down to 750 ft., but is not found at 800 ft. As seen on the 7th level the ore is largely chalcocite, with a good deal of galena scattered through it. This body of ore was first struck in running a drift around the caved ground, after going through what had formerly been taken for the hanging-wall of the ore-shoot. The body of copper-ore thus struck has constituted the principal wealth of the mine in recent years. It is said to be from 2 to 5, or even 20 ft. thick, and up to 200 ft. in horizontal length. It apparently rests directly on the chert or "rhyolite," somewhat as indicated in the section (Fig. 10).

FIG. 10.



E.-W. Section of Horn-Silver Mine.

Shipments of copper-ore from this body are said to have averaged 25 per cent. of copper, and in some cases to have run as high as 40 per cent. Although no ores of copper or zinc are

said to have been found in the lower levels, the walls of the drift running through the chert, which forms a large proportion of the fault-material on the 11th level, were observed to be covered with chalcanthite, and in some cases with goslarite. The latter material is very abundant, in unusually long, fibrous, silky clusters, throughout the lower levels of the mine.

It is thus evident that this mine presents an unusually fine instance of secondary enrichment in the middle levels by zinc and copper minerals which have been leached down from the upper part of the deposit as decomposition and erosion have gradually progressed. The mine is essentially a dry one, but not so extremely dry as the Delamar; considerable water being collected in the lowest levels. It is one of unusual interest, both mineralogically and structurally. The region has evidently been subjected to intense dynamic action since the intrusion of the igneous rocks; and the structure in detail is by no means as simple or as readily recognized as the broad outlines given above might lead one to assume. It does not seem probable, moreover, that the great ore-shoot mentioned above is the only one in the region; and it is very possible that a careful geological and structural study of the ground opened might lead to the discovery of others; but it was useless to undertake such a study without complete and accurate maps of all the underground workings.

Some Recently Exploited Deposits of Wolframite in the Black Hills of South Dakota.*

BY J. D. IRVING, WASHINGTON, D. C.

(Richmond Meeting, February, 1901.)

In the summer of 1899 there appeared in the Black Hills *Mining Review*† a short note announcing the discovery of certain deposits of wolframite in the vicinity of Lead City and Yellow creek, Lawrence co., South Dakota.

---

* Published by permission of the Director of the United States Geological Survey.

† *Black Hills Mining Review*, vol. v., No. 32, pp. 14, 15.

This paper, by Alexander Forsyth, of the Rapid City School of Mines, gave a brief account of the discovery and occurrence of the ore and discussed its concentration, but did not embody the rėsults of any very extensive geologic investigation. A further notice of these deposits is to be found in the *Mineral Industry* for 1899.* During the summer of that year the writer, while engaged in field-work for the U. S. Geological Survey, made a study of these ore-bodies, the results of which are stated in the present paper.

History.—For some years prior to 1899 large quantities of what was locally known as "black iron" were mined, together with refractory siliceous gold-ore, from workings in the vicinity of Lead City and from the west side of Yellow creek. In most cases, this material contained very low values in gold, and was sorted from the ore, so that it accumulated in considerable amount on the waste-heaps of the mines. Some of that from Yellow creek, however, is reported to have yielded workable gold-values. This was shipped to the smelter and there treated among other basic ores, without suspicion of its special value. In January, 1899, however, its great weight attracted the attention of a local mineral collector; and a few simple tests served to reveal its true character. Its importance was quickly recognized by manufacturers of tungsten-steel; and the exploitation of the deposits has now developed into an industry which, although not extensive, has yielded considerable profits to individual owners.

Geology.—As has been repeatedly observed,† the general geologic character of the Black Hills is that of an elevated area of roughly elliptical outline, comprising a central core of metamorphic crystalline rocks, about which are grouped, in rudely concentric belts, strata of later geologic age dipping away in all directions from what is termed by Newton‡ the "elevatory axis or region of the hills." The general trend of this central core is due N. and S., but at its northern extremity it turns quite abruptly NW., forming a sort of geological *cul-de-sac*,

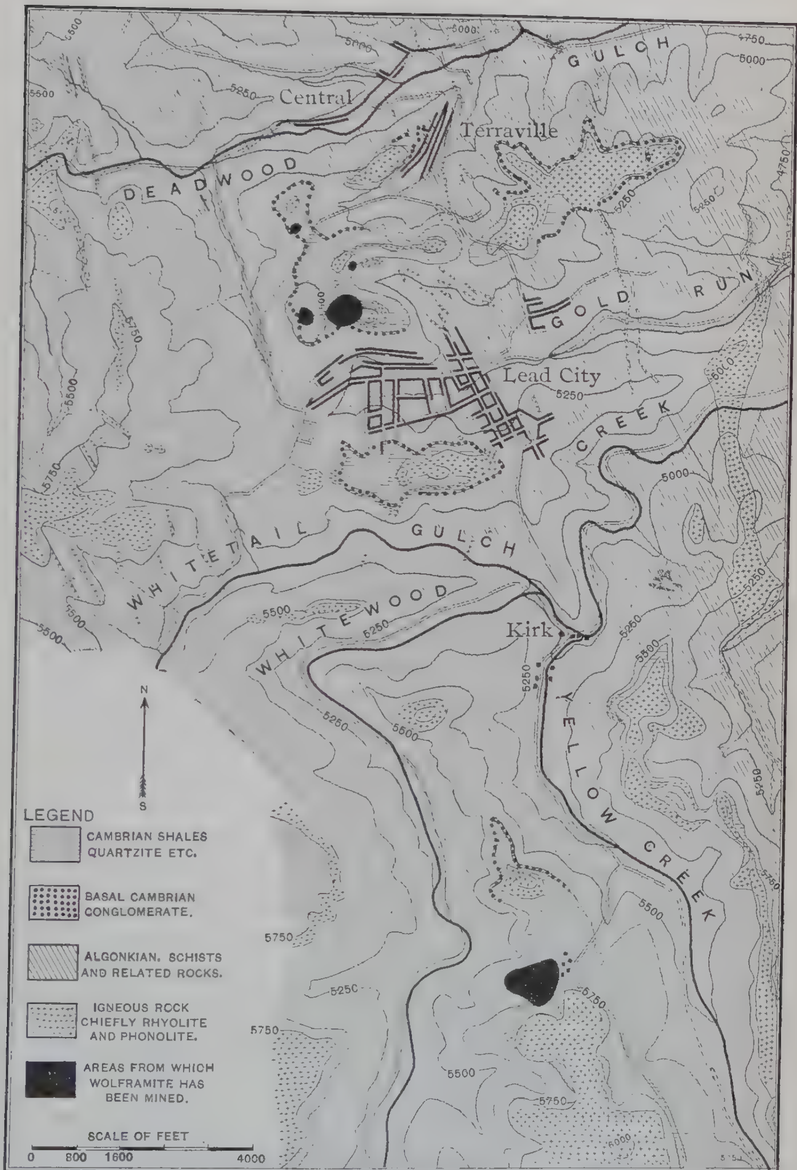
---

* Rothwell's *Mineral Industry*, vol. vii. (1899), pp. 719, 720.

† "Ore-Deposits of the Black Hills of Dakota," by F. R. Carpenter, *Trans.*, xvii., 570.

‡ "The Geology and Resources of the Black Hills of Dakota," *U. S. Geographical and Geological Survey of the Rocky Mountain Region*, p. 39.

FIG. 1.



Geological Map of the Vicinity of Lead City, South Dakota.
(Geology by T. A. Jaggar and J. M. Boutwell.)

shut in on three sides by later strata, but separated from the main area of schists to the south by only a narrow belt of Cambrian rocks and their included masses of porphyry. Throughout this northern area, erosion has not cut so deeply into the crystalline schists as further south; so that, besides the rude belt of enclosing Cambrian strata, isolated outliers of that formation cap the higher hills within its confines. Nearly at the center of this area of crystalline rocks and just south of one of these detached remnants is Lead City. The map accompanying this paper shows this town in the northern portion, and extends south so as to include several narrow tongue-like areas of Cambrian that project northward into the central region of schists as thin cappings on the divides between the deeply incised valleys.

The metamorphic rocks of this area comprise a series of schists, phyllites, quartzites, amphibolites and other varieties of crystalline rocks, everywhere tilted to a high angle, showing an advanced stage of metamorphism, and enclosing numerous intruded dikes of eruptive rock, chiefly rhyolite and phonolite. Unconformably upon the eroded surface of these upturned schists lie the nearly horizontal strata of the Cambrian, having at the base a conglomerate which varies from practically 0 to 22 ft. in thickness, and above this (in certain portions of the Lead City area), layers of quartzite and loosely compacted sand. These beds are in some places highly auriferous. They constitute the so-called "fossil-placers" so well described by Devereux,* and were in former years an important source of revenue in the Hills. Indeed, at two of the mines mentioned in this paper, the Durango and the Harrison, wolframite has been extracted through the shafts and tunnels once used in exploiting these auriferous gravels. In the Yellow Creek area the basal conglomerate is thin and non-auriferous, and passes by gradual transitions into a hard, dense quartzite, the two together constituting a bed which varies from 10 to 25 ft. in thickness. Resting upon this quartzite (or, where that is poorly developed, directly upon the auriferous conglomerates) lie the ore-bearing beds, composed of a rather loose, shaly

---

* "The Occurrence of Gold in the Potsdam Formation, Black Hills, Dakota," *Trans.*, x., 465, *et seq.*

material, very heavily charged with iron oxides and the carbonates of lime and magnesia, and, in some places, so decomposed as to be a mere soft, earthy gouge, often stained with black oxide of manganese. If traced, however, to localities where decomposition is not so far advanced, it is found to be a dense, reddish-brown rock, showing many glistening facets of lime-magnesia carbonates, and sometimes exhibiting a well-marked stratified structure, due to the interposition of thin, and often discontinuous, layers of argillaceous shale. Microscopic and chemical examination have shown this rock to be a crystalline dolomite. In other districts, where it is deeply buried and entirely unaltered, it is grayish-blue, and contains considerable glauconite. This ore-bearing rock is known among miners as "sand-rock." The transition between it and the underlying quartzite is sometimes sharp; but in the two districts where the wolframite has been found, it is gradual; the sand-grains increasing in abundance as we go downward until the dolomite appears merely as a cement, and finally disappears altogether. For this reason, and also because silicification has always occurred together with the deposition of the wolframite, the calcareous nature of the ore-bearing rocks has often been overlooked, and the deposits have been spoken of as "mineralized quartzite." This misconception should be avoided, because the process of mineralization has been one of replacement, and the original material replaced was in large part lime-magnesia carbonate, whether present as a cement or forming the body of the rock.

Above the dolomitic beds generally occur layers of shale, which become much more argillaceous, and often contain considerable glauconite, as one passes vertically upward. Above these shales, both in the vicinity of Lead City and Yellow creek, are found remnants of a rhyolite sheet, showing, in many cases, a well-developed columnar structure..

Occurrence of the Wolframite.—This mineral has been found, thus far, at two localities. The first is upon the Cambrian outlier immediately N. of Lead City, on the top of the high hill which forms the crest of the divide between Gold Run and Deadwood Gulch; the second is in the narrow tongue-like area of Cambrian which, as a thin capping on the divide between Yellow and Whitewood creeks, projects N. into the central area

of schists. The two lie in a line which trends about N. 25° to 30° W., and follows very closely the strike of the schistosity of the upturned metamorphic rocks below. In the latter rocks, just E. of the northern deposits, are the open cuts of the Homestake mine, which lie in a line nearly parallel to that connecting the wolframite-areas, and on a great mineralized, gold-bearing zone in the schists. The Yellow creek occurrences lie just west of the projection of this zone, bearing the same relation.

The wolframite occurs in flat, horizontal but rather irregular masses, from nearly 0 to 2 feet thick. They frequently cover considerable areas, of which perhaps the largest so far discovered may be 20 to 30 sq. ft.; but they are so extremely irregular that it is difficult to form an exact estimate of their lateral extent. These wolframite-bodies are intimately associated with the flat masses or "shoots" of refractory siliceous ore, so extensively developed in the Black Hills of late years, which consist of an extremely hard, brittle rock, composed chiefly of secondary silica, and carrying, when unoxidized, pyrite, fluorite, barite, and occasionally gypsum. Many cavities occur, lined with druses of minute quartz crystals, with clusters of purple or green fluorite or tabular crystals of barite. Oxidized portions are heavily stained with oxide of iron and contain much infiltrated calcite, while the cavities often show drusy linings of jarosite. In the areas where the wolframite is found, the siliceous ore is always oxidized (no traces of original sulphides being discernible), and contains more barite than that from the other and more typical localities (the barite frequently forming as much as 50 per cent. of the rock), and is usually of coarser texture. In form these bodies of siliceous ore are flat, channel-shaped masses, having, in the districts under discussion, a thickness of from 1 or 2 to 15 ft., and ranging in length from 2 ft. to as much (in rare instances) as 500 ft., while the width is from 5 or 6 to 50 ft. or more.* The ore is usually banded, the banding being continuous with the bedding-planes of the adjoining strata, and the shoots occur along lines of fracture termed "verticals," on either side of which the dolomite has been replaced from a

* These dimensions refer only to the siliceous ore-bodies found in the Lead City and Yellow Creek areas—the wolframite districts. The "shoots" in the Ruby Basin district are often of much greater size.

fraction of an inch up to 12 ft. in distance. Careful investigation of the ore-bodies of this type shows that they are replacements of the dolomitic beds by silica, pyrite and other accessory minerals. The mineralizing waters seem to have gained access to the soluble beds through the fractures, and to have been confined to them by overlying impervious beds.

The wolframite is to be considered more in the nature of a basic phase of these ores than as a separate and distinct deposit, for it occurs always in intimate association with them. At times it forms a rim around the outer edge of the siliceous ore-shoots, often extending inward and upward so as to form a thin capping to that ore. It thus appears as a sort of envelope to the siliceous-ore mass, which it encloses, or nearly encloses, on all except the lower side. Margins of this kind are often from 2 to 2.5 ft. thick, but the capping portion is generally thinner. At other times the wolframite occurs in irregular masses, scattered through the siliceous ore, or in stringers and thin, contorted layers in the partially-silicified dolomite. In the Wasp No. 2 mine in Yellow Creek, it was observed in lenticular or kidney-shaped masses in the shaly dolomite. An excellent instance of the first or envelope-type of occurrence is to be seen in the Harrison mine, near Lead City. In the Two Strike mine in the Yellow Creek area it was seen in thin, irregular layers replacing the uppermost and more calcareous portion of the basal Cambrian quartzite.

In general the ore is separated from the non-mineralized rock by a fairly sharp line of demarcation; but in not a few cases it grades off so that the ore becomes leaner and passes by scarcely perceptible transitions into the country-rock. In almost all cases considerable silicification has extended beyond the wolframite-deposition, so that, without the aid of the microscope, it is difficult to distinguish the original rock from quartzite.

Character of the Ore.—As taken from the mines, the wolframite is a dense, black, massive rock of fine, granular texture and of great weight. It closely resembles a fine-grained magnetite; but its greater specific gravity and slightly brownish streak, together with the associated minerals, generally render its identification possible. The component grains are, in the majority of cases, about $\frac{1}{32}$ in. in diameter, and always exhibit brilliant

cleavage-faces. In the portions having coarser texture, the grains are $\frac{1}{8}$ to $\frac{1}{4}$ in. across, and have slightly curved surfaces with an extremely brilliant metallic luster. They do not possess crystalline boundaries except when the replacement has been but partial or when crystals project into cavities. Radiating aggregates or single tabular crystals of barite are present in considerable abundance embedded in the body of the wolframite, but are more sparsely distributed in the more massive portions. They have always attained a perfect crystalline development, which shows that they are the earlier formed ingredients of the ore. Irregular cavities or vugs, such as are generally to be seen in deposits originating from the replacement of one mineral by another, are present throughout the ore in great numbers. These are of all sizes, some of them very intricate in form, and often of considerable aggregate volume. Their interior surfaces are usually coated with small but well-formed crystals of wolframite, not unlike marcasite in their form and the manner of their grouping, and with crystal-druses of yellowish or bright green scheelite. The crystals of the latter mineral are often of great beauty and perfection. In some cases, cavities are filled with white or glassy crystals of barite. In a few instances, the leaner wolframite from Yellow Creek shows long slender crystals of stibnite, radiating from a common center, much in the manner of the spicules of a radiolarian.

Despite the decomposed and gouge-like character of the country-rock, alteration has not generally taken place to any noticeable degree. When the ore has been long exposed to atmospheric conditions, however, a mineral of gold-yellow color, in glistening druses of extremely minute crystals, very often coats the surface. This has been considered by Forsyth* as suggestive of tungstite, or tungsten trioxide; but none of that collected by the writer gave satisfactory results to tests for tungsten; and its true character has not yet been determined.

Under the microscope, the ore, when very pure, shows little besides the dense, opaque wolframite. Occasionally, interstitial masses of clear, glassy quartz are observed, filling the spaces formed by the crystal-faces of wolframite. When sufficiently

---

* *Op. cit.*, p. 15.

lean to permit the use of transmitted light, however, the wolframite may be seen to be made up of innumerable small crystals, which are generally well developed, but interfere with one another at their extremities. There are thus left between the wolframite individuals many irregular spaces, always bounded by plane surfaces and usually filled, either with secondary quartz or by grains of original detrital quartz, about which enlargements caused by later added silica have formed complete crystals. In some specimens large crystals of barite are to be seen. Scheelite occurs interstitial to the wolframite. Sections of the ore cut from the portion where it passes into the unreplaced rock show a moderately abrupt transition from massive wolframite to partially-replaced material, with interlocking crystals, which gradually become more sparsely scattered, until they finally disappear in the barren rock. The latter is generally heavily silicified beyond the limits of the wolframite, so that the microscope shows, if polarized light be used, that the rock is almost wholly composed of silica. If, however, the polarizer be removed, nothing can be

Analyses of Wolframite Ore.

	I. Per cent.	II. Per cent.
SiO_2,	12.87	9.60
WO_3,	61.50	61.70
Fe_2O_3,	3.85	12.67*
FeO,	9.18	
Al_2O_3,	0.52	
MnO,	8.21	7.21
CaO,	0.93	5.39
SrO,	0.02	
BaO,	0.04	
$K_2O + Na_2O + Li_2O$,	0.08	
H_2O,	0.20†	
H_2O,	0.87‡	
As_2O_5,	1.25	
P_2O_5,	0.12	
V_2O_5,	Trace.	0.10§
S or SO_3,	Trace.	
	99.64	

Assays of I.—Gold, 0.05 oz. per ton; silver, 0.25 oz. per ton.
Extremely minute traces of Mg, Zn, Cu, Sb and Sn were also found.

* Determined as Fe_2O_3, includes FeO.
† Up to 105° C.
‡ Above 105° C.
§ Approximate.

seen but the sharp outlines of irregular rhombs such as constitute the body of the usual type of dolomite before mineralization; the original carbonate having been replaced with such delicacy that its structure has been perfectly preserved.

Chemistry.—The foregoing analyses were made by Mr. W. F. Hillebrand in the laboratory of the United States Geological Survey. Both analyses are of specimens of the purer and more massive portions of the wolframite. No. I. is of a specimen taken from the Two Strike mine in Yellow Creek. It is complete and may be assumed to show the average composition of the wolframite. No. II. is a specimen from the Harrison mine, near Lead City. It is only partial, but is inserted to show the relatively high percentage of lime.

While it is not possible to calculate from these analyses the exact mineral composition of the ore, on account of the difficulty of determining the form in which the minor ingredients are present, the relative proportions of the more important constituents may be roughly calculated, as follows:

Proportions of Principal Minerals.

	I.	II.
Wolframite $(FeMn)O.WO_3$,	75.60	51.58
Quartz, SiO_2,	12.54	9.60
Scheelite, $CaO.WO_3$,	4.77	27.68
Barite, $BaO.SO_3$,	0.06	
Ferric Oxide, FeO,	3.85	
Water, H_2O,	0.20	
Arsenic Oxide,	1.25	
Residual clay (Kaolin),	1.34	

It will at once appear from these tables that the ore is contaminated chiefly by scheelite and quartz. The first has probably been formed by the combination of some of the tungstic acid with the original lime of the mineralized beds, while the silica may have been either a portion of the unreplaced quartz, which occurs in grains throughout the country-rock, or later-formed silica, introduced at the time of mineralization.

For metallurgical purposes, it is possible that the minor constituents, such as arsenic, vanadium, and especially phosphorus, may seriously impair the utility of the ore; but the writer is not sufficiently familiar with the present practice to venture an opinion upon this point. Analysis No. II. is interesting as showing a relatively large proportion of scheelite.

Concentration.—As only the purer and more massive ore carries a sufficiently high percentage of tungstic acid to meet the requirements of the smelters, it has been found necessary to concentrate a considerable portion of the material mined. At some of the mines the crude method of hand-sorting and trimming off of gangue by hammers is adopted. For this purpose a considerable number of men must be employed and the cost must be heavy; but the value of the ore seems to justify even this expense. Of late, experiments have been made with various wet methods of concentration; and Forsyth* discusses in some detail the several processes which have been tried. He shows that the chief difficulty lies in the production of slimes, and that, in cases where considerable gold-values occur in the ore, they pass into the concentrates and not into the tailings. This difficulty is, however, of minor importance, as the ore rarely carries any appreciable amount of precious metals. At the time that the mines were visited it was suggested that these ores, which are quite strongly magnetic, might readily be separated by the Wetherill concentrator; and in the opinion of the writer the difficulties that have been encountered might thus be obviated. It will be interesting to note the result of such experiments.

Value.—The *Mineral Industry* for 1899 shows that the tungsten-market is a somewhat fluctuating one, and it is not therefore possible to give any exact idea of the value of the ore; but it is reported to have been sold at from $100 to $250 per ton, according to the percentage of tungstic acid present and the date of sale.†

Discussion.—Wolframite is not a common mineral; and its occurrence in bodies of sufficient size to be profitably worked is rare. Deposits have been found recently in Arizona and Nevada, and at a few other localities in the United States.‡

So far as the writer has been able to determine, the associations in which wolframite ores are found are two:

1. As a constituent of pegmatitic granites, usually of the type

* *Black Hills Mining Review*, vol. v., No. 32, p. 15.

† *Black Hills Mining Review*, vol. v., No. 32, p. 15.

‡ A very comprehensive summary of the tungsten-deposits of the United States may be found in the 21st Annual Report of the U. S. Geol. Survey, Part VI., *Mineral Resources*, for 1899–1900, pp. 300–304.

known as greisen, and frequently more or less closely associated with ores of tin. Such deposits occur in the Black Hills in the Nigger Hill and Etta tin-districts, but the material is there crystalline, and is generally believed to have resulted from pneumatolytic action.

2. In quartz-veins, in granite or other rock of related character. Most of the more recent discoveries belong in this class; for instance, those in the Dragoon Mts. of Arizona; at Murray, Shoshone co., Idaho; Osceola, Nevada; San Juan co., Colo.,* etc.

The familiar case of the wolframite of the Cornwall tin-region is in part comparable with both of these types.

It will at once appear that neither of these two classes of deposits bears any resemblance to those under discussion, which are, so far as the writer is able to ascertain, a unique occurrence. That they are formed through the gradual replacement of the country-rock by wolframite seems to the writer to be clearly indicated by the character of the ore, the nature of the beds in which it is found, and the metasomatic origin of the ores with which it is inseparably connected. First, the wolframite itself is filled with cavities of irregular form and distribution such as are almost always to be observed in ores formed by replacement where the aggregate volume of the mineral introduced is smaller than that of the original rock; secondly, the beds in which the ore occurs are composed chiefly of magnesian limestone, often quite impure, it is true, but of a prevailingly soluble character; thirdly, the wolframite is an integral part of the shoots of siliceous gold-ore, the metasomatic origin of which has been conclusively proved by careful microscopic study.

As regards the source from which the tungsten-minerals have been derived, no positive conclusion can be formed; but the relation of the deposits to the geology and to the other ore-bodies of the neighborhood seems to furnish some evidence as to their derivation. They are found at two rather widely separated localities on the W. side of the outcrop of the Homestake ore-body. Along this line there has taken place, first, the heavy mineralization of the Algonkian rocks, which has produced that well-known ore-body; secondly, the mineralization of the Cambrian above, resulting in the formation of sili-

* *Mineral Resources*, 1899–1900, pp. 300–304.

ceous gold-ores, which are richer and contain a more varied assortment of secondary minerals than ores of similar character away from the Homestake lode; and, thirdly, the formation of the wolframite-ores themselves. It seems, then, that the line of strike of the Homestake lode is also a line along which mineralization has been both varied and unusually intense. During this extensive mineralization, the circulation of waters capable of dissolving the metallic contents of the surrounding rocks must have been active. That these waters were, in the case of the siliceous ores, and hence in the case of the wolframite, ascending waters is proved by the concentration of these deposits beneath impervious beds. It is therefore not unreasonable to suppose that if wolframite occurred in the Algonkian rocks at some point below the deposits now worked, just as it occurs in its normal relations at other points within the Hills, the action of ascending thermal waters upon this material should have given rise to the mineral-bearing solutions which carried the wolframite up to its present position, and, there encountering rock sufficiently soluble to admit of metasomatic interchange, should have redeposited their metallic contents.

If this be true, it may be said that there are two distinct but genetically related types of wolframite-deposit in this region:

1. That which characteristically occurs in the granitic and related rocks of the Algonkian, and is comparable with the greater number of such deposits from other parts of the world. This is instanced by the wolframite from Nigger Hill and the Etta tin-mines in the southern Black Hills. It may be termed a "primary" deposit.

2. That which has been formed by the solution of bodies of the first type, and a metasomatic redeposition of the material in stratigraphically higher beds. This may be termed "secondary."

The limited extent of the areas of ore-bearing rock in the vicinity of these ores, so far as they have been yet traced, indicates that their commercial future is not great. It is not impossible that other bodies of wolframite, of similar character, may be found upon some of the areas of Cambrian strata in the same general region; but if the apparent relation of the ores to the line of outcrop of the Homestake lode has any significance, it is doubtful whether prospecting in these more remote localities will prove successful.

Notes on the Geology of Southeastern Arizona.

BY E. T. DUMBLE, HOUSTON, TEXAS.

(Richmond Meeting, February, 1901.)

I. INTRODUCTION.

IN continuation of the geological work begun in Sonora, Mexico, a partial account of which has already been given in the *Transactions* of the Institute,* a similar reconnaissance was made of Cochise county, Arizona, and a part of the Whetstone mountains.

The investigation resulted in the identification of beds of similar age and character to those of the Sonora region, and in the discovery of interesting deposits, which, so far as I can ascertain from the literature at my command, have not been described heretofore.

Route.—Starting from Nogales, we followed the railroad to Crittenden, and then drove to the southeastern slope of the Whetstones. After a brief examination of some reported coal-beds we continued our route, following the wagon-road between the Whetstones and the Mustang mountains to Huachuca, and eastward to Tombstone. Crossing the Dragoon mountains at South Pass, we traveled south and west by way of Turquoise and Antelope Spring into the road from Tombstone to Bisbee. Our route over the Mule mountains lay through Mule Pass and Bisbee, where we stopped a day or two. Thence, crossing Sulphur Spring valley, we drove around the southern end of the Swisshelms, and N. through the valley between these mountains and the Chiricahuas, to White river. From that point our way led through Rucker cañon into the San Simon valley, then northward along the eastern face of the Chiricahuas, and by way of Fort Bowie to Willcox, Arizona, from which place we returned to Nogales.

It was greatly regretted that the extremely wet weather prevented us from including in our examination the Huachuca

* *Trans.*, xxix., 122 *et seq.*

mountains, where we had hoped to find better exposures of the Triassic and Cretaceous rocks than we found in the Mule mountains.

II. Geology.

Representatives of all the Cenozoic formations differentiated in the Sonora region were also observed in Arizona.

1. *Cenozoic :—(a) Pleistocene.*

The drift, stream-gravel, silts, etc., which are referred to this period were observed along the route; but few places showed any differences from those which have already been described, and these differences were unimportant.

1. *Cenozoic :—(b) Tertiary.*

The Tertiary deposits of the region include rocks of the Baucari stage, or lake-deposits, and the two volcanic complexes designated as the Nogales and Trincheras beds respectively, which were described in my "Notes on the Geology of Sonora," previously referred to.

The Baucari Division.—The most notable exposures of the Baucari which were observed on the trip were those of the Santa Cruz river, east of Calabasas. Here the deposits present their usual even bedded character and dip at low angles with little or no faulting. While in a way resembling the upper conglomerate of the Nogales series, the lower beds of the Baucari are much more thinly bedded and of a more clayey matrix. The grains of quartz are rounded, as are the pebbles, and the lowest beds are thin-bedded grits splitting into plates with square fracture, very different from the more massive structure and irregular fracture of the Nogales.

On the road to Rawlins we passed through one valley, the hills along the sides of which were 100 ft. or more in height, and the cañons cutting these banks showed nothing beside the even-bedded lake deposits.

The surface of the Baucari is much eroded in places, and the brown beds of massive conglomerate of the Pleistocene overlie it.

The divide between the Santa Cruz river and its branch, Sonoita creek, shows the Baucari lying along the foot of the

Patagonia mountains in horizontal beds, more or less conglomeratic, with the pebbles running in lines of stratification, and sometimes forming the sole evidence of bedding. Here, too, the character of these beds as lake-basin deposits was plainly apparent.

The Nogales Division.—The principal rock-exposures between Nogales and our first camp on the Santa Cruz river, three miles east of Calabasas, were of the tufaceous agglomerate belonging to the Nogales beds, underlain by beds of more compact lavas. A difference was noticed between the deposits here and at the type locality, in the materials entering into the agglomerate, the included pebbles showing, in addition to the felsitic materials of the agglomerate at Nogales, blocks of material of porphyritic structure, lavas and other agglomerates, so that it is here more nearly a tufaceous conglomerate.

At some places the agglomerate contains only pebbles of small size, and is in beds, 12 to 18 in. thick, which furnish a very good building material and are quarried for that purpose.

The beds have a general dip toward the SE.; but the inclination varies considerably.

At the Santa Cruz river the Nogales agglomerate rests unconformably on a highly pegmatitic pink granite with inclusions or segregations of fine-grained brown granite. Between the granite and the agglomerate appears a white feldspathic rock, probably a partially kaolinized rhyolite or rhyolitic tuff. The granite carries large crystals of feldspar and very large ones of quartz, but the mica, which is of light color, is in small particles. The granite is cut by NW.–SE. dikes of a trachytic rock of greenish-gray color. The granite is, in color and structure, unlike anything previously seen in connection with the Nogales beds, and may possibly be older than they; but its position and general character permit its reference to them.

The next exposure of note was on the approach to the Chiracahua mountains from the pass at the S. end of the Swisshelms, where we found the foot-hills to be composed of beds similar in all respects to the Nogales. The section here shows a heavy deposit of rhyolite, light gray to light purple in color, weathering dark brown, granular to porphyritic in texture, and made up principally of light-colored feldspars with a few grains of quartz. Different beds (for it appears to be bedded) show

different colors and textures, and weather differently. Some 200 ft. of these beds was exposed here, but the base was not shown. Overlying it, without apparent unconformity, is a tufaceous rhyolite-agglomerate, partly kaolinized, and for the most part quite friable, although in places it is still firm, and forms heavy bluffs and huge boulders. It carries quantities of an opaline feldspar. The thickness here is 100 ft. or more. A granitoid rhyolite, with pink and white feldspars, a little quartz and a little white silvery mica, overlies the agglomerate. It resembles that at Nogales very closely, and here, as there, is overlain by the Nogales conglomerate. A further resemblance is found in the dikes of basaltic rock which cut the granitoid rhyolite.

As we pass up White river toward Rucker cañon, we find on either side high banks of Quaternary gravel. When the first line of hills is reached, their N. end appears covered with a heavy black basaltic lava, showing columnar structure, and overlying unconformably the Nogales conglomerate, which, in almost horizontal beds, constitutes the major portion of the hills. From here to the mouth of the cañon proper, all the hills are composed of this conglomerate. Its contact with the underlying rhyolite is shown just N. of the mouth of the cañon. The unconformity which has been so frequently noticed between these deposits is very evident here; for, while the conglomerate maintains its approximately horizontal stratification, the rhyolites dip SW. at an angle of 15°. The contact here is the same as that noted in the foot-hills, namely, between the conglomerate and a tufaceous rhyolite with opaline feldspar. Below this the hard porphyritic rhyolite comes in, underlain by the agglomerate, which is light-colored and weathers light gray or very nearly white.

To the south the agglomerates are clearly interstratified with harder beds of igneous material, and also of conglomerate, grit and sand. Even clayey beds are not lacking. The agglomerates rest upon a granitic rock, from which they dip away; and remnants of them rest upon the granite in nearly horizontal beds, as though the granite were intrusive.

To the eastward the bedded rhyolites of the lower Nogales come in; and between them and Rucker we find the andesites and agglomerates of the Trincheras beds.

The Trincheras Division.—Exposures of rocks believed to belong to this series were observed in Sonoita cañon. They consist principally of lavas and tuffs, and are overlain, unconformably, by the Nogales beds, the rhyolites having evidently been much disturbed prior to the deposition of the later sediments. The rhyolite shows bedding in some places, but is massive at others. Some basaltic rock and dark porphyritic deposits were also observed, and a granitic rock with gray inclusions—apparently a granitoid rhyolite.

East of Richardson's ranch, the hills show a very peculiar limestone. It is of light color, weathering gray, and very much corroded and perforated, like the limestone at Casita, Sonora. It is peculiar in that while in places it is a creamy semi-crystalline limestone, it carries quantities of siliceous pebbles, and is in other places a true conglomerate with calcareous matrix, its pebbles and boulders comprising igneous rocks, limestones, siliceous pebbles, etc. I think it represents the base of the Trincheras in this region.

To this division I would doubtfully refer the porphyritic rock and limestone found on the E. slope of the Dragoon mountains, near South Pass. The porphyries are kaolinized and somewhat mineralized. The finding of a large boulder of copper-ore a mile south of the pass led to considerable prospecting on these kaolinized streaks, and this was still in progress at the time of my visit.

The porphyry of the Turquoise hills belongs with this, both by its character and position. These hills lie in two ranges, the eastern one being made up of the Dragoon quartzite (to be described later), but showing this porphyry on its western face. The valley between the two ranges and most of the western range is of this porphyry, the hills being capped with limestone, the age of which we failed to determine, as we did not succeed in finding any fossils.

The turquoise-deposits, from which the hills get their name, occur in the porphyry, apparently along definite horizons. The contact of the porphyry and the limestone is also characterized by the iron-capping of veins of carbonate of lead, carrying silver and gold.

There is a possibility that this rock may belong to the Lista Blanca; but from its general appearance and associations I think it is Trincheras.

The Antelope hills show a light-colored porphyritic rock, capped by a rhyolite of light purplish color, carrying opaline feldspars. These beds apparently belong to the Trincheras, have a very considerable thickness, and show distinct bedding-planes.

In the pass S. of the Swisshelms there appear, in connection with the limestones, large inclusions of red chert and cherty or quartzitic conglomerate. They seem to occupy openings in the limestone, as though filling the mouth of an old spring; and branches run out in cracks in the limestone in various directions from the neck.

A red porphyry containing crystals of white feldspar also occurs here, forming high points and ridges, and having a general NW.–SE. strike. While it may be the eruptive accompanying the uplift which formed these mountains, the fact that limestones dip toward it and not away from it seems to negative this supposition.

Along the road, just N. of the pass, a mass of gray porphyritic material was observed in contact with this red porphyry. It appeared to be the same as, or at least similar to, the rock observed in the Antelope hills.

Two miles west of the Powers ranch, at the Great American mine, the quartzite or cherty conglomerate is again exposed. It here attains a considerable thickness and overlies the Carboniferous limestone. While it is largely conglomeratic, and at times contains fragments of limestone similar to that underlying it, it does not always show such structure; and there are places where it is difficult to make out the exact relations existing between it and the limestone. It is overlain by the Antelope hills porphyry with the opaline feldspar, and is more or less mineralized in many places. Rich pockets of ore occur in the more porous portions of the rock. The ores are chlorides and sulphides of silver.

In Rucker cañon the relations of the various divisions of the Cenozoic were very clearly shown. Overlying the limestones of the Bisbee Cretaceous with their characteristic fossils, we find the conglomerate and volcanic complex of the Trincheras, followed by the beds of the Nogales division, and these by later lava-flows and Quaternary deposits.

The Sawmill cañon section exhibits good exposures of the

Trincheras beds and the underlying Bisbee. The general section of the Trincheras here consists of: A pink granitic rock, with inclusions of other materials. This has a thickness of over 500 ft., and is underlain by 50 ft. of a dark gray agglomerate, under which there is a series of andesitic tuffs, agglomerates and flows, which aggregate 100 ft. in thickness. These rest upon a granitoid andesite passing into a massive hornblende andesite, 300 ft. thick. The base, as usual, is the conglomerate, which is here 200 ft. thick, and made up of boulders of limestone, sandstone, quartzite, etc., in a limy clay matrix. The limestone fragments show fossils both of the Carboniferous and Cretaceous beds; and the conglomerate was found resting upon different horizons of the Bisbee beds, showing its entire unconformity with that formation.

The eastern flank of the Chiricahuas shows practically the same section, and at the mouth of the cañon these rocks are succeeded by the Nogales and later beds, just as they are on the W. From this cañon northward to Cave creek, all the principal exposures appeared to be referable to the Trincheras.

The Cave creek section shows massive rhyolitic rocks 500 ft. in thickness, underlain by 40 ft. of tufaceous agglomerate, and this by 100 ft. of massive rhyolitic agglomerate, of porphyritic texture. Then come alternations of massive rhyolite, agglomerate and tuff for 200 ft. These rest upon a purple porphyritic agglomerate more than 500 ft. thick, and this upon a gray feldspathic rock—probably an andesite—which has a thickness of 100 ft. This forms the base of the volcanic rocks, and rests upon the limestone conglomerate.

The conglomerate at this locality is of the usual character, and here rests upon a quartzite which is separated from the underlying Carboniferous limestone by a white kaolinized material.

The two volcanic complexes here described as Nogales and Trincheras present similar characters in that they are composed of volcanic rocks which occur as beds of feldspathic materials in the form of massive andesites or rhyolites; agglomerates, both massive and tufaceous; and volcanic breccias and conglomerates. Occasionally, scoriaceous beds are found; but these are exceptional. Each has also, interbedded with these volcanic rocks, sedimentary deposits of sand, clay, and even

limestone. They are different, however, in appearance, and are not so hard to tell the one from the other, generally speaking, as are the Trincheras and Lista Blanca. The Nogales beds are much more rhyolitic, siliceous or quartzitic than the Trincheras; are more inclined to light colors; and the granular portions show numerous inclusions or dikes of darker and more basic material. Altogether, the appearance of the Nogales in Arizona is much the same as in Sonora, where it was first studied.

There is a possibility that further study will separate the Nogales conglomerate from this series, with which it almost always seems to be unconformable; but as there are, so far, no data for assigning anything more than their relative ages to any of these unfossiliferous beds, they are left for the present as first described.

The Trincheras beds in Arizona differ somewhat from those of Sonora; but the difference is due merely to locality. The original observation was made at a point where there was a great volcanic conglomerate with interbedded lava flows and limestones. The overlying andesites and rhyolites were not seen in such thickness as they show in Arizona, and as I have since found them to show in central Sonora. Still the materials entering into the basal conglomerate is the same at both localities.

These beds are of special importance from their connection with the ore-deposits of the region. So far as I have seen it, all of the "red rock" and greenstone of the Mexican miners is referable to these deposits, and in the rhyolitic tuffs which occur in them there are examples of stockwerk veins which, I think, will become the bases of considerable industries when they are properly understood.

They are here referred to the Tertiary, because of their stratigraphic relation to the Cretaceous; but as they have only been found resting upon beds of Lower Cretaceous age, they may be in part, at least, of somewhat older date than that assigned to them.

2. *Mesozoic: (a) Cretaceous.*

Exposures of deposits which could be positively referred to the Cretaceous were only seen at Bisbee and in Rucker cañon.

The first exposure was in a creek near the grave-yard at

Bisbee. The underlying rock is a feldspathic material, massive and of felsitic texture. It is nearly white, seamed and streaked in all directions with ferruginous lines, which give it a reddish appearance. It carries nodules of quartz in places, but shows no porphyritic texture, as do the rocks observed NW. of Bisbee. It shows neither bedding nor dip, but has more of the appearance of a boss of rhyolitic material. This is apparently the same rock which occurs in connection with the extensive copper deposits of this locality.

Overlying this rhyolite there is a bed of quartzite, quite dense and glassy, with ferruginous streaks and, in places, a distinct narrow banding, as though originally deposited as sandy flags. It has a thickness of 100 ft. and dips 45° N.

Unconformably succeeding the quartzite is a bed of conglomerate 20 ft. and upwards in thickness, dipping 30° E. The pebbles are of quartzite and mica schist; and the matrix is a lime or limy clay. It forms the base of a series of clays and sands which are well shown up the creek, and which have a thickness of more than 1000 ft.

The red clayey sands of the first 200 to 300 ft. of the section closely resemble some of the red tuffs of the Lista Blanca, and may have been derived from them. They carry lime concretions and show splotches of greenish color in connection with them, thereby increasing the superficial resemblance of this portion of the beds to some of the Lista Blanca agglomerates. Above these red clayey sands there is a series of interbedded red and gray sands 150 to 200 ft. thick. The remaining portion of the section as shown here is principally thin- to heavy-bedded gray sand. No fossils were found here; but from the connection of these beds with those observed a little further E. in the same mountains, I place them at the base of the Cretaceous.

About 1.5 miles southeast of Bisbee we again find these rocks exposed, together with others, making altogether a section of some 3000 ft., unconformably overlying the older (Paleozoic) rocks.

The basal 1200 ft. of the section is, as stated, the same as that just described near Bisbee. Immediately above this is a bed of limestone filled with *Trigonia*, *Natica*, etc., which is followed by a yellow limestone with *Exogyra*. The Trigonias are

of the type of *T. streeruwitzii*, Cragin, of the Trans-Pecos section of the Cretaceous. The *Exogyra* limestone is followed by sand and clayey sand, and this by a band of purplish material resembling a tuff, which shows the effects of erosion prior to the deposition of the succeeding beds.

Above this we have a series of interbedded sands, clays and limestones, sands prevailing toward the base and limestones toward the top. The sands are gray in color and usually thin-bedded. The clays are limy, shaly to slaty, brown to black in color, and fossiliferous. The limestones weather yellow to gray, and occur both thin-bedded and massive. They are not cherty, and are very full of fossils, some of the beds being little more than a mass of broken oyster-shells with only enough cementing material to hold them together. Oysters 6 to 7 in. in length were found, the most of them being square-beaked, although a few were found with pointed-beaks.

The most characteristic bed, perhaps, is a massive limestone 40 ft. thick, which is largely made up of forms resembling *Caprotina* or *Requiena*. A very noticeable feature of this bed is its precipitous weathering. It is overlain by 60 ft. of heavy-bedded limestone which is also fossiliferous. From the purple band at the base to the top of this limestone there is a total thickness of 500 ft.

A number of fragments of the silicified trunks of dicotyledonous trees were found on the hillside below the massive limestone. These were, presumably, derived from the various sand-beds, but none were seen in place. Succeeding the limestone and without any seeming unconformity there is a series of interbedded sands and clays or clayey sands. The sands at the base are quartzitic, and the clays are shaly to slaty in structure and dark brown to black in color. Above them are red sands, clays, shales or slates, interbedded with gray sandstones or quartzites. The gray sands are strongly false-bedded, giving the impression at first sight of standing nearly or quite on edge. They constitute more than one-half of the series at this point. The other sands are of different shades of brown, thin to massive, occasionally cross-bedded and ripple-marked, with very little, if any, mica. In a few places they pass into a grit, but are usually fine-grained. They carry copper-impregnations in one or two horizons. These sandy beds have a thickness of at

least 1200 ft., and form the hills along the pass to Sulphur Spring valley. At places they show a coarser grain than the beds of the section given, grit and even conglomerate occurring. Quantities of white quartz are found scattered on the hillsides, derived from the numerous streaks or veins which abound in the beds.

Pending the definite correlation of these Cretaceous deposits with those of other localities I propose for them the name of the Bisbee beds.

In composition these beds are not unlike those of Northern Sonora, on the Cabullona river; but the fossils seem to be entirely different. Those in Northern Sonora appear to me to resemble more nearly the regular Texas types of Lower Cretaceous forms, while those of the Bisbee beds approach more nearly the fauna found in the section west of Sierra Blanca and in the vicinity of Malone, Texas. Mr. T. W. Stanton writes me that some similar fossils have been sent to him by one of the members of the Boundary Commission, but I do not know the exact locality from which they were obtained.

In Rucker cañon the uppermost beds of the Cretaceous which came under our notice were sandstones and shales. Probably 200 ft. of this material was seen, underlain by the limestones, which in turn rested upon the interbedded sands and clays, as before. The thickness of the limestone beds here was obscured by faulting; but southeast of Rucker they appear to have a thickness considerably in excess of that at Bisbee. At the southern extremity of the range there are some high hills, which, at a distance, appear to be made up almost entirely of these limestones. East of Rucker the country flattens so rapidly that the lower rocks do not come to the surface.

2. *Mesozoic: (b) Triassic.*

The Mesozoic rocks seem to cover a considerable stretch of country adjacent to the S. end of the Whetstone mountains, and apparently to underlie the larger part of the valleys between these and other ranges. But so far as observed they only reach into the flanks of the mountains proper, the mass of which is usually composed of older rocks.

The base of the series, as shown in the Whetstone mountains, consists of 100 ft. of gray or greenish-gray clay-shale, in-

terbedded with small bands of sandstone and limestone. These clays carry many imprints of leaves, some of which appear to us to resemble closely those of the Triassic slates at La Barranca, Sonora. These shales are followed by a bed of grit, and this by a thin bed of argillaceous limestone, containing a number of bivalve shells resembling those of San Marcial, Sonora, which include *Panopæa remondii*, Meek, and other forms. Another bed of grit separates this from a seam of blue limestone, largely made up of small *gryphæa*-like forms which were not sufficiently well preserved for identification. From the resemblance of the fossils we are inclined to put this portion of the beds at least in the Triassic.

These are followed by a series of clays and sandstones with interbedded light-colored rhyolitic lavas or tuffs, of porphyritic texture, kaolinized in places. The sands, which predominate in the middle and at the top of the section, comprise not only beds of pure sand, but others variously mixed with clay and lime. They vary from the extremely fine-grained "whetstone-rock" to coarse-grained sand, grits and conglomerates. They are usually even-bedded, and are shaly to massive in structure; but some cross-bedding was observed. The upper beds are principally light-colored, but bright colors, pink, red and brown, predominate toward the base.

The clays are largely chocolate in color, shaly to medium-bedded, with concretions of lime or bands of disconnected lenses of limy clay, which may sometimes form beds of impure limestone from 50 to 100 ft. long. In some parts of the beds the clay is very compact and resembles some of the consolidated tuffs of the La Barranca and Cabullona districts, having also the concretionary weathering of such rocks. One of the beds of tuff carries a band of agate.

The only fossils found in the series was a lot of imprints of a bivalve shell in an impure limestone. They were so badly preserved, however, that they could not be identified.

It is this upper series of sands and clays, with a thickness of 5000 ft. or more, which forms the mesa and valley. The rocks dip gently S. 25° W.

In the basal clays there is a bed of very black clay which has been prospected for coal. A tunnel was driven, some 500 ft. long, of which 200 ft. was in this shale and the remainder in

sandstone. The shale in the tunnel is extremely bright, and glistens not unlike a bed of coal. It carries concretions or "niggerheads" which resemble in occurrence and structure the concretionary coal of Palo Pinto seam, near San Xavier, Sonora; but here the coal is replaced by clay, with a center of iron pyrites.

The Lista Blanca Division.—The Lista Blanca complex, which we found in such extensive deposits in Sonora, between the Cretaceous and Triassic sedimentaries, is not so well shown in the Arizona region. The exposures which we believe to belong to this series of rocks are those between the Mustang mountains and Huachuca; those on the E. flank of the Dragoons near South Pass; and those observed at the S. end of that range, and toward Antelope spring.

In general appearance and composition the Trincheras and Lista Blanca are so similar that it is often hard to determine to which series a given exposure may belong, unless there is a determining outside factor. They are both largely andesitic, and the agglomerates are much alike. The Trincheras, however, seems to contain more beds of a massive character of green and gray colors, and these usually have a fresher appearance than similar beds of the Lista Blanca. I have so far found but one locality at which both series were present, with the Cretaceous beds separating them, and so far have not had an opportunity to compare them as closely as I hope to do. The Cretaceous appears so seldom that one is fortunate to find a single contact, either overlying one complex or underlying the other, and thus definitely settle its position. When the two complexes come together with no other beds between, as they sometimes do, it is hard, if not impossible, to tell just where one ends and the other begins.

Between the Mustang mountains and Fairbanks we observed several exposures of volcanic agglomerates which we think belong to the Lista Blanca. A volcanic breccia was also observed between Fairbanks and Tombstone, greenish-gray in color, porphyritic in texture, and carrying both mica and hornblende. The enclosed fragments are all of felsitic texture; and the boulders show no signs of rounding at all. As we saw no contact of this rock with sedimentary beds, its reference to this horizon is made on the ground of its general character.

From the west, the approach to South Pass is over beds of gray hornblendic andesite and volcanic conglomerates, of which the boulders are principally andesites, with smaller fragments of siliceous rocks. A single exposure was noted, of a sandstone underlying this rock. This andesitic material, which was porphyritic at first, became more granular nearer the mountains, until the latter texture finally prevailed entirely. It was cut by a basaltic dike at one locality. This granite is of very coarse grain, with large feldspars, and is considerably decomposed. It is succeeded to the east by purple and brown bedded andesites, which form the main body of a hill N. of the road. Up to this point the rocks resemble those of the Lista Blanca very closely, but the granitic rock below them seems to belong to a much earlier period.

As we passed around a low hill at the SE. point of the Dragoon mountains, we found that the granite of that hill was overlain near its base by a granite which may be Lista Blanca. The granular texture is found at the road-crossing of a small water course, but farther up this creek it is more tufaceous. In the more distinctly granitic portion we noted the occurrence of imbedded pebbles of limestone. The tuff of the Lista is covered by a rhyolite which does not appear to belong to the same series.

3. *Paleozoic.*

The Carboniferous rocks have a very wide distribution and considerable thickness in this region, and contain enough fossils to permit their identification at most exposures. I think the best section can be had in the Whetstone mountains.

The evidence of the presence of the Devonian is in the few fossils obtained from the lower limestones of the South Pass section of the Dragoon mountains. Our trip was a very hurried one, and the time to search for fossils was extremely limited. I think closer collection would give many more forms, not only from this locality, but from the N. face of the Mule mountains as well. If there be deposits of the Silurian, they will probably be found near the NE. corner of the Mule mountain block.

All that we could secure regarding the earlier rocks is too indefinite to warrant the drawing of conclusions as to their age.

Upper Carboniferous and Devonian.—The main body of the Whetstone mountains, so far as they came within this examination, is composed of sandstones and limestones of the Carboniferous age. Our observations were made at points some distance apart, and the relations of some of the beds were not closely made out; but the fossils obtained were fully sufficient to establish their age.

On the W. side of the mountains, underlying the Triassic, we found 400 ft. or more of limestones, light gray to blue in color, the latter predominating. These limestones are usually heavy-bedded or massive, and are very cherty. The chert in the lower portion of the limestone was white as quartz; but higher up it was of a gray color. The limestones show much corrosion on their weathered surface, and the cylindrical openings first observed in the limestone of Casita, Sonora, were found here, also, although not so numerous or so large.

The flint nodules carry numerous fossils, and the same forms occur in quantities in the limestone. A few were collected and sent to Dr. Schuchert of the U. S. National Museum for identification. He reports them to belong to the following species: *Productus* app. new sp. No. 1; *P. nebraskensis; P. semireticulatus*, var. *ivisi; Seminula argentea; Archæocidaris* spines.

The limestone is underlain by beds of sandstone 400 ft., or more, thick. The sands are of different degrees of fineness and compactness. The general dip is 25 degrees N. 25° W.

The SE. side of the mountains shows a series of interbedded sands and limestones differing from the last, and, I think, underlying them. The sands are nearly all fine-grained and friable, and there are a number of bands of limestone interbedded with them. These beds have a thickness of 500 ft., as shown by the exposures.

Two miles S. of the Whetstones there is a small group of mountains near the track of the New Mexico and Arizona railroad, known as the Mustangs. They appear to be, both in structure and composition, a part of the Whetstones, although separated from them by this wide valley.

The rocks are cherty Carboniferous limestones, which are cut through and disturbed by bodies of rhyolitic rock. From their character and the fossils they carry, these limestones seem to be the equivalents of the upper limestones of the Whetstones.

These rocks have here a thickness of 1000 ft. The limestone is very massive, and in the various peaks stands out in bluffs a hundred feet or more in height. Fossils of the common Upper Carboniferous species are very abundant, and are fairly well preserved. These mountains closely resemble, in the character of their rock material and in their topographic features, those of similar age in Western Texas.

The fossils determined by Dr. Schuchert were: *Seminula argentea ; Pugnax utah ; Productus* app. new. sp. No. 1.; *Reticularia perplexa ; Archæocidaris* plate; *Bellerophon* cfr. *capax.*

Viewed from a point E. of the railroad, the Mustangs and the Whetstones appear to represent the result of a series of folds having axes running NNE. and SSW. The character of the folds is well brought out by the line of massive limestone at the top, the curves of which are clearly traceable through the mountains. There is, in connection with these folds, a series of step-faults with downthrow to the westward.

In the Dragoon mountains the Carboniferous occurs resting upon rocks, the fossils from which indicate the middle Devonian. So far as we observed, there was no marked unconformity between them. The total series has a thickness of 600 ft., and rests upon the Dragoon quartzite. The limestones at the base are interbedded with sandstone, they then form limy flags, and finally merge into massive beds. They carry flints throughout, and become very cherty toward the top. At the base the dip is nearly vertical; but this gradually shades off to about 35° toward NE.

Just E. of the main exposure of these limestones there is a hill of Carboniferous limestone, so situated as to appear to be absolutely unconformable with the beds above-mentioned; and the difference noted in dip and character of rock at the time led us to believe that it was much later than those beds. It appears, however, from the study of the fossils obtained, that it is of the same age as the upper portion of the main limestone belt. As already remarked, there appeared to be perfect conformity in the 600 ft. of limestone in the main mountain; but the fossils collected from the base are of middle Devonian age, while the others are all referred to the Upper Carboniferous.

The fossils determined by Dr. Schuchert, from the limestone near the Dragoon quartzite, were: *Cladapora* near *labriosa ; C.*

near *roemeri;* from the limestone above that, *Campophyllum torquium; Syringopora*, distinct from *multattenuata;* and from the hill on the E., *Spirifer camratus.*

The N. face of the Mule mountains presents a series of limestones, heavy-bedded to massive, and of very considerable thickness. They appear to be the equivalents of the heavy limestones of the Dragoons; and the few fossils secured bear out this reference, being Upper Carboniferous forms. Those from this portion of the range, identified by Dr. Schuchert, are: *Archæocidaris* plate; *Septopora biserialis; Productus pertenuis; Naticopsis altonensis.*

No Devonian forms were found here, but they may easily exist in the lower part of the section, which lies toward the E., and which we did not have time to examine.

The rocks at the entrance to Mule Pass cañon appear to belong to this same series, and continue to be the only rocks exposed for a distance of two or three miles as we traverse the pass. We then come upon a repetition of the section observed below it in the South Pass of Dragoon mountains. Here the Carboniferous limestones are tilted sharply SW. and cut by extrusions of a porphyritic rock, which in places also overlies them. The limestones rest upon the Dragoon quartzite. The flaggy condition of the lower part of the limestone, near its contact with the quartzite, was also noted here.

The close resemblance of the two sections makes it pretty certain that both Carboniferous and Devonian will be found here when closer examination is made.

The flags show, on some surfaces, a reticulated marking which somewhat resembles the remains of broad leaves, but it is probably simply a segregation of siliceous materials.

The pass at the S. end of the Swisshelm mountains shows the massive limestones of the Carboniferous, similar to those seen in the Dragoon and Mule mountains. They have usually a rather dirty gray color, and are very cherty, the cherts taking peculiar forms and frequently running in lines parallel to the bedding-planes. Sometimes the cherts seem to have replaced forms of sponges or corals; but they are usually so badly weathered that nothing definite can be made of them. Many beds seem practically devoid of fossils, except that now and then a fragment of a crinoid stem or a broken shell may be

seen on a weathered surface. Other beds show a variety of fossils. One or two horizons seem to be especially marked by the *Archæocidaris*, as large numbers of stems, spines, plates, etc., of this genus occur in them. Others are largely made up of encrinite stems, while occasionally a bed will present a number of brachiopod forms.

Seminula argentea and a fragment of a coral which is possibly a *Campophyllum* were the only forms identified by Dr. Schuchert from the very imperfect specimens collected at this locality.

In the Chiricahua mountains, on Cave creek, above Mr. Reed's house, we found exposures of platy limestones closely resembling that at the base of these beds.

North of this, between Cave creek and Turkey creek, the exposures of Carboniferous limestones are very satisfactory. They dip SW. from 30° to 45°; and the section is repeated by the occurrence of faults.

The upper limestones appear to have a thickness of 1200 ft., and are underlain by 300 ft. of limy clays with interbedded limestones. Fossils are abundant; but, as is the case throughout this area, they are all siliceous pseudomorphs, and are not well preserved. Dr. Schuchert determined the following species: *Syringopora multattenuata; Campophyllum torquium* (?); *Lophophyllum proliferum; Reticeolaria perplexa; Dielasma bovidens; Seminula argentea; Euomphalus subquadratus; Meekella striatacostata;* and fragments of *Productus*, *Spirifer*, and *Derbya*—so that the horizon is established as Upper Carboniferous. There appears to be a slight unconformity near the middle of the beds, but it may be due to faulting or slipping.

Pre-Devonian.—The rocks which underlie the Devonian in the Dragoon mountains, and which we found to occur both in the Mule and Chiricahua mountains, were not differentiated.

The main mass of the Dragoons, where we crossed them, begins with a coarse-grained brownish granite. This is succeeded by 100 ft. of mica-schist, which stands practically vertical. The mica-schist is followed by 40 ft. of limestone, and this by an andesitic rock, probably 100 ft. in thickness at this point. Then comes a series of sandstones and quartzites 400 ft. in thickness, to which we gave the name of the Dragoon quartzite. This is followed by the limestones of the Devonian. These rocks form the main body of the mountain, and around

the flanks are deposited the eruptive rocks, described elsewhere as Lista Blanca, which have a much gentler inclination.

The Dragoon quartzite is of all degrees of fineness from conglomerate down. It stands on edge, with a NW.–SE. strike.

In the valley E. of the Turquoise hills there is a granite which appears to be that of the main mountains, as seen in South Pass; and this forms the E. face of one of the higher mountains of the range, and is continued in a low hill, around which the road passes to Antelope springs.

In the Mule mountains, the limestones rest upon the Dragoon quartzite, and the bed of porphyritic andesite (?) which there appeared between the quartzite and the mica-schist is also present. The mica-schist has a thickness of about 300 ft., and rests directly upon the granite in most places, although at times an intrusive porphyry intervenes.

At Turkey creek, near Gayleyville, there is in the hillsides a very rotten, coarse-grained, porphyritic granite. It is overlain by a greenish limy sandstone and conglomerate. This is followed by about 300 ft. of interbedded slates and sandstones. The slates bear imprints of leaves, which appear to be principally grasses. The sands carry fragments of silicified twigs and branches. The lime bands are occasionally as much as a foot in thickness. Overlying this, there is between 50 and 100 feet of massive sandstone, interbedded and capped with clays, which merge imperceptibly into the base of the 200 ft. of the overlying lavas and porphyries. At one locality the granite is associated with contorted beds of limestone and quartzite.

The entrance to Wood's cañon shows some of these same beds, and the road into Bowie appears to repeat the same section. The quartzites which here rest upon the granite, however, seem to be much thicker than elsewhere, and are interbedded with sandy shales. The overlying limes or limy clays exhibit a shaly structure, with some beds of a more massive character. Above these come the heavy-bedded limestones, with softer bands, which are, in turn, succeeded by a series of black, limy shales, not observed elsewhere.

From the fault just N. of Bowie, which brings the granite up to the side of these beds, to the flat between Dos Cabezas and Willcox, we found few exposures of the granite and of the lower quartzite and limestone.

III. Summary.

A general section of the rocks observed on this trip may be shown in the following table:

Pleistocene.

Gravels, silts, etc.

Black basaltic lava, columnar.

Tertiary.

Nogales Beds.

1. Conglomerate.
2. White tuff with opaline feldspars.
3. Interbedded rhyolitic agglomerates—principally porphyritic and tufaceous.
4. Thin-bedded tuff, agglomerates and grit with some clay bands.
5. Dark gray and brown agglomerates, partly porphyritic, partly tuff. Top bed containing much agate.
6. Light-colored tuffs and agglomerates, with some harder bands and some strata of grit. Bedded throughout, base especially being very even-bedded.

Trincheras Beds.

1. Pink granitic rock, with inclusions of other materials.
2. Dark gray agglomerate.
3. Andesitic tuffs, agglomerates and flows.
4. Granitoid andesite, underlain by massive hornblende andesite.
5. Conglomerate of boulders of limestone, quartzite, etc., in a limy clay matrix.

Cretaceous.

(*Bisbee Beds.*)

1. Interbedded sands and clays.
2. Interbedded limestones, clays and sands, with oysters at base and *caprotina*, etc., at top.
3. Limestones and clays, with *trigonia*, *exogyra*, etc.
4. Interbedded sands and clays, with conglomerate at base.

Triassic.

1. Lista Blanca complex.
2. Interbedded sands and clays, with little lime.

Carboniferous.

Limestone, sands and clays, with Upper Carboniferous fossils.

Devonian.

Limestone, with middle Devonian fossils.

Older Rocks.

Dragoon quartzite and underlying limestone, mica schist and granite.

Remarks upon Surveying Instruments, with Special Reference to the Paper of Mr. Dunbar D. Scott on the Evolution of Mine-Surveying Instruments, and to its Discussions.

BY H. D. HOSKOLD, BUENOS AIRES, S. A.

(Mexican Meeting, November, 1901.)

It was not for the purpose of asserting any superior knowledge or authority, but simply of clearing up, in greater detail, some points casually mentioned in Mr. Scott's able paper, that the writer entered, some two years ago, into the discussion which that paper initiated. In such matters there is always room for differences of judgment, as well as for additional data, which may modify or complete the conclusions even of the best authorities.

Those who are immersed in the duties of practical administration or work in the field, and who, being remote from the great scientific national libraries, are obliged to rely on their private collections, and to supplement them by their recollections of earlier studies, labor under special disadvantages in such a discussion; and it must be to the scientific and engineering world a matter for gratitude that Mr. Lyman has been willing to give the benefit of his advantages in this respect.

Mr. Lyman would, however, doubtless at once disclaim the conclusion that his masterly summary constitutes "the last word" on this subject, and welcome further evidence, comment and criticism, such as the various contributors may continue to offer. This, therefore, is the motive, and must be the excuse, of the introduction by the writer of the following observations.

The Miners' Dial.—Many years since, the writer employed a miners' dial, older in type than Fig. 12,* but without any attached spirit-level, made by Thomas Jones, a pupil of the great Ramsden. Jones was one of the old London makers and opticians, and enjoyed great reputation for accuracy in the con-

* *Trans.*, xxviii., 692.

struction of large circles for astronomical uses. He was born in 1775, and died in 1852.* This old-fashioned miners' dial was mounted for use upon a three-legged stand, each leg of which could be unscrewed at the middle, in order to adapt it to various heights in mine-workings. In its original form the instrument was awkward for use on steep inclined planes; and, in order to render it more widely serviceable, the writer attached to one side of the compass-box a double-sliding plain sight, which could be raised vertically when it was necessary to take the magnetic bearing of lines upon severe inclines. At that period it was attempted to obtain vertical angles by turning down the compass and sights, so as to form a right-angle, with a line passing through the center of the ball-and-socket joint, and the vertical angles were roughly indicated by a suspended plumb-bob line upon a divided circle which was engraved upon the brass cover of the instrument. This statement refers to work performed more than 50 years ago; but even to-day such an instrument would be preferable to the hanging-compass. There are, however, at the present time, instruments of this type constructed in a superior manner.

In former technical works the writer has frequently expressed his opinion, based upon much experience, adverse to the general use of the magnetic needle, and believes that nothing would be gained by continuing the discussion of that point. Those who do not care to accept the opinions of others must follow their own practice, and may have cause, some day, to repent their choice.

Plotting with the Compass.—It is difficult to believe that Mr. Lyman's warning on this subject was really necessary. The practice to which he refers was followed in Cornwall some 60 years ago, but only by persons not possessed of better means or not acquainted with such superior methods as were used by others.

Supposed Gravitation-Error.—Mr. Lyman presents† an elaborate argument against the suggestion, in the writer's last contribution,‡ that the deflection of the plumb-line by neighboring mountain-masses would affect the accuracy of compass-surveys; but it must be confessed that this theory was advanced upon

---

* Mackenzie's *Universal Biography*, p. 51.

† *Trans.*, xxxi., 61.

‡ *Trans.*, xxxi., 40.

the authority of others; and it must be concluded that any error of survey due to this cause would be, under ordinary circumstances, too small for serious consideration. Nevertheless, it is necessary to note that in South America the chain of the Andes, from the equator to Cape Horn, occupies an immense area, and rises to great altitudes.

Ramsden's Dividing-Engine.—Ramsden, one of the most celebrated makers of mathematical instruments, was born in 1735, and at the age of 25 began business as an optician and instrument-maker. As the writer now believes, he invented his memorable dividing-engine in 1773 (not 1760)*; but, as Mr. Lyman correctly observes, no description of it was published before 1777. Ramsden encountered many difficulties, and was occupied for many years in completing this grand invention. In a paper upon the division of instruments, read before the Philosophical Society in 1809, Mr. Edward Troughton said:

"Ramsden's well-known method of dividing by the engine unites so much accuracy and facility that a better can hardly be wished for . . . in the division of instruments of moderate radii. It was well suited to the time in which it appeared; a time when the improvements in nautical astronomy and the growing commerce of our country called for a number of reflecting instruments, which never could have been supplied had it been necessary to divide them by hand."

Assyrian Maps and Surveying.—Mr. Lyman is correct in believing that his Fig. 151† represents "the best Babylonian map that has yet been discovered . . . . not newer than about 650 B.C." The brick tablet from which Fig. 151 was obtained exists in the British Museum, London; and, from the information published by that institution, it would appear that the old Assyrian map which Mr. Lyman has introduced and discussed must have been constructed long prior to 650 B.C.

The following important details are obtained from various tablets now in the British Museum:

"Here are exhibited two interesting series of tablets, which were inscribed during the rule of the kings of the Second Dynasties of Babylon. They are from about B.C. 2400 to B.C. 2100. The first series (Nos. 1 to 15) consists of a number of lists of fields or estates, with their measurement and statistics. The measurement gives the length and breadth of each field or estate, as well as the total superficial area. The care with which these lists are drawn up indicates that

* In *Trans.*, xxviii., 694, and xxix., 960, 1760 is an error. See xxxi., 89, 90.
† *Trans.*, xxxi., 57, 58.

they form part of a larger survey of the cultivable districts near the rivers and canals, and round about the cities of Southern Babylon, and there is little doubt that they supplied the data upon which the system of taxation and collection of revenue employed by the Babylonian kings and priests was based. . . . .

"The ability to work out such calculations was of great value in a country like Babylon, where the areas and boundaries of fields and estates were constantly changing, owing to the frequent inundations of the Tigris and Euphrates."*

Another very important document proving that the art of surveying was well-known and practiced, is a tablet giving an account of an "Agreement between the governments of Assyria and Babylonia," probably drawn up in the reign of Assur-banipal, King of Assyria, B.C. 668–625, to settle disputes concerning the boundaries of the two kingdoms. The document comprises a series of brief notices of the conflicts and alliances which took place between the Assyrians and Babylonians from B.C. 1600 to B.C. 800, and is usually known as the Synchronous History. Puzur Asher, King of Assyria, and Burnaburiach, King of Babylon, discussed and fixed the boundaries of both kingdoms, 625 B.C. There are also two other tablets of importance, one of which is an "Assyrian astrolabe, or an instrument for making astrological calculations and forecasting nativities," and the other is a "fragment of another Assyrian astrolabe."

The writer has already directed attention to the extraordinary drawings found upon the walls of the ancient copper-mines of Wady Magerah, which were worked in the time of Senefura, 4000 to 3900 B.C., as also to a plan of an ancient Egyptian gold-mine, drawn upon papyrus, B.C. 1400, and preserved in the Turin Museum.†

In all probability, such works as those indicated in the various records cited were not executed by the sole use of a straight-line measuring-instrument. As already observed, circular astrolabes were used in ancient Assyria for astronomical purposes; and there is no reason for supposing that it never occurred to the Assyrians and Babylonians to apply such instruments to the measurement of horizontal as well as vertical angles. Some kind of circular instrument, although rough in construction, must have been employed in obtaining data for the construction of the Egyptian underground map of a gold-

* *A Guide to the Babylonian and Assyrian Antiquities.* By Prof. E. A. Wallis Budge (1900).

† *Trans.*, xxix., 957.

mine, previously referred to; and in the formation of the extensive *cadastral* maps of the rivers, canals and States round about Babylon, also mentioned above.

Prof. De Morgan.—De Morgan was one of the ablest mathematicians of his time; but he was also a man of strong prejudice in reference to the ancients. However, he could know no more of them than other equally learned men. Proclus, no doubt, knew all about the philosophical and mathematical lore of those who had preceded him by many centuries, and, consequently, he was in the best position to appreciate and record the facts.

The Vertical Circle.—The writer cannot agree with Mr. Lyman* as to the "important additional advantage" of a full vertical circle attached to a class of instrument such as that of Mr. Stanley's, viz.: "that it enables the constructor to test the placing of the vernier so thoroughly as to make it trustworthy." In the case under notice, the full circle gives the maker no more aid in this respect than a semicircle with an adjustable vernier, operated or adjusted in opposite directions by two screws, according to the practice of the best English manufacturers. It appears from Fig. 63 † that Stanley's vertical circle revolves with the telescope, being attached to the cradle carrying the telescope. The vernier and its attached metal bar must, therefore, be a fixture screwed to the horizontal axis; and as there is but a single vernier, placed on the upper part of the circle, the lower half of the circle cannot by any means offer a check upon the placing of that single vernier, which in itself has no means of being adjusted.

Mr. Stanley tells us that the lower half of the circle has a circular scale of difference between the hypothenuse and the base, read by an index; and, besides, its principal use is to aid the clamping-operations.

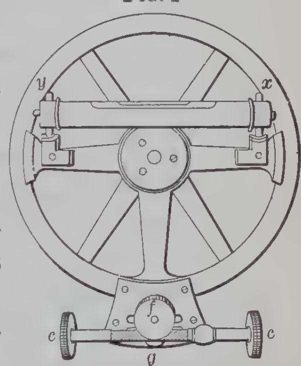
To render this instrument more practical, it would be advisable to attach a spirit-level to the vernier-arm, just above the end of the horizontal axis, as at $x\ y$, Fig. 1, and, by preference, to have verniers placed opposite each other, instead of Mr. Stanley's single one. Vertical angles would then be more "trustworthy." For this object, however, as before suggested,

* *Trans.*, xxxi., 91.

† *Trans.*, xxix., 939.

a semicircle with an adjustable vernier would have been less complicated, far preferable, and more useful. As the case stands, there is no "trustworthiness" in the vertical angles obtained by this instrument, for the reason that, if the vernier- and circle-zeros are adjusted by the spirit-bubble attached to the telescope before any work is commenced, the moment the telescope is brought into use there is no spirit-level to refer to, in order to determine whether the zero of the vernier remains in the perpendicular line or not, and, consequently, accuracy in this respect must be left to chance; besides, in such a case, the same operations must be repeated at each station. It is easy to see that a slight displacement of the instrument could not, under the circumstances, be detected, and that, in such a case, the reading of a vertical angle would be vitiated. In no case should the accuracy of the vertical line passing through the vernier-zero be referred to the short levels inside the compass-box, supposing that such exist. The vernier-bar may not be so nicely fixed that its zero would be in the perpendicular line when the spirit-bubbles in the compass-box are supposed to be level.

Fig. 1



Vertical Circle, with Spirit-Level Attached.

The vernier-bar of the vertical circle in Mr. Stanley's instrument, as in all good instruments, should therefore have its own attached independent spirit-level, in order to determine the perpendicularity when the telescope is in movement; besides, it offers greater economy in time and facility in working.

Conical or Sloping Graduations.—Mr. Lyman, admitting the superior convenience of such graduation to the observer, says:

"But the sloping graduations are disliked by instrument-makers, because more troublesome from the increased difficulty of correcting the centering and of getting the vernier precise; and therefore repairs are much more expensive."*

This may be the case among the American makers with

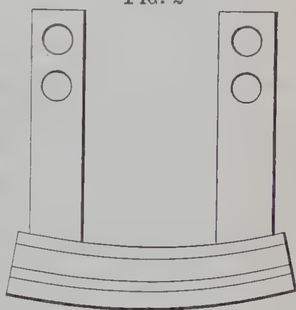
* *Trans.*, xxxi., 91.

whom Mr. Lyman is acquainted, but it cannot be said of the best European instrument-makers, especially those of greatest repute in England. The writer is fully aware that circles were formerly divided upon the level surface or flat, for surveying-purposes, and this practice was continued for a considerable time; but after a good deal of experience, engineers and surveyors did not like the plan, and, consequently, the conical or sloping divisions were introduced, and have been continued for a great number of years. When, however, the circles are large, as in some of Troughton & Simms's 36-in. instruments, where there is plenty of room to read with perpendicular micrometrical microscopes, the divisions are on a flat surface. By these makers, no more difficulty is encountered in centering verniers so as to agree with sloping divisions than there is when the divisions are placed upon a flat or level surface. In his communication with various mathematical instrument-makers for more than fifty years, the writer never heard of any such objection as that mentioned by Mr. Lyman. The writer possesses instruments of from 3 to 9 in. diameter, with conical or sloping divisions, none of which, after many years of constant use, requires repairs. Any such deterioration as that described by Mr. Lyman is due to the inferior construction of some of the principal internal parts of an instrument. For example, in all instruments made by the best English makers, the central solid vertical axis is constructed with a collar or shoulder turned out of the solid metal at its upper extremity, and this collar is screwed to the underside of the vernier-circle in such a way that the axis is fixed precisely at the centre of the circle. Around the upper part of this axis, and in contact with the collar noted, another one is turned out of the solid metal, and this smaller collar or flange rests immediately upon a corresponding one, turned out of the solid metal at the inside of the horizontal divided circle; and at its center, surrounding the upper part of the hollow axis of this circle, which also, in its turn, is screwed to the centre of the divided circle, the upper part of it penetrates through the circle to a point level with the collar indicated; therefore the collar and part of the hollow axis project upward a little above the general level of the metal forming the interior part of the divided circle. When, therefore, the solid vertical axis is placed in the

hollow one, the central collars described sustain the weight of the upper part of the instrument, and thé outer circumference, or underside of the vernier-circle, does not rest upon the upper edge of the divided horizontal circle; consequently, there is no rubbing or friction of those parts.

Each of the verniers is constructed with two strong springs forming part of it (see Fig. 2), and these springs are adjusted and screwed to the underside of the upper horizontal circle in such a manner as to agree, to the utmost nicety, with the upper exterior extreme edge of the sloping divisions upon the horizontal circle. Above each vernier a notch or space, a little longer than the length of the vernier, is cut out of the underside of the vernier-circle, so that in case of wear between the central collars, calculated to lower the outer edge of the vernier circle, any resulting pressure would cause the verniers to rise an equal amount, but they would still retain a nice contact upon the edge of the divided circle, without undue friction. Even in such an extreme case, which the writer, however, has never known to occur with good instruments, the wearing of the internal central collar would not be sufficient to lower the vernier-circle upon the edge of the divided circle; so that under no condition is there any injurious friction or abrasion of the metal forming the divided edge of the verniers and the upper edge of the horizontal or divided circle.

FIG. 2



Vernier with Springs.

On the other hand, many of the makers of inferior and cheaper instruments follow the practice of soldering the verniers to the upper horizontal circle, and level with the general horizontal plane of its lower side; and as their attention is not so much directed to the accurate construction of the interior of the instrument as to the exterior, the verniers and other parts of the circle to which they are attached are generally in contact with the upper part of the horizontal divided circle, resulting in the wearing away of the metal, which disarranges the divisions on the vernier and the divided circle, and consequently produces a worthless instrument in a comparatively short space of time.

Reading Conical Divisions.—These divisions can be read with the greatest facility, because the reading microscopes are so attached that the line of sight through each falls perpendicularly upon the divisions of the vernier and circle. This line would fall $50\frac{1}{2}$ degrees, in a vertical plane, from a vertical line drawn through that part of the vernier and divided circle under view. There is, therefore, no inconvenience or obstacle to prevent the placing of the head and face of the observer so as to obtain an easy and accurate reading. As the above angle indicates, the conical divisions have an advantage in this respect over those on the flat surface. Mr. Lyman is apparently somewhat reluctant to admit this; at least, he will only say that the former are, indeed, "slightly easier to read." But the writer maintains that the difference is manifestly more important, and that "a great deal" would be nearer the truth than "slightly."

Reading Flat Divisions.—This case is exactly the reverse of the foregoing. In reading the divisions upon the flat surface of small instruments, and near the circumference of a horizontal circle placed near it, the line of sight must fall perpendicularly upon the graduations of the vernier and graduated circle; and for an accurate reading the observer's face and head must be brought near enough to permit the eye to perceive the divisions; but in doing this the head of the observer would, in the case of some construction of instruments, come in contact alternately with the two ends of the telescope, or side of the standards, unless, indeed, the observer raised the eye- or the object-end of the telescope (as the case might be), to give more room. The writer has frequently seen some of the North American transit-theodolites, in which the verniers were placed at points upon the horizontal circle directly below the eye- and object-ends of the telescope, thus offering the obstacles mentioned. This may explain why the diameter of such instruments is generally larger than those of the English ones with conical divisions. Some other American instruments, however, have the horizontal verniers placed upon the horizontal circle at right angles to the direction of the telescope. Even in that case, the room for reading is much less than when the divisions are placed upon a sloping or conical limb. But it is natural that Mr. Lyman should assert the superiority of the instruments of his own country.

Leveling-Screws.—In saying that "the growing sentiment in England is in favor of three leveling-screws," Mr. Stanley is understating the truth. Such a sentiment (if it be no more) has already grown, and is fully established. Three leveling-screws have been employed for leveling theodolites and spirit-levels for more than 40 years. Longer ago than that, Troughton & Simms made instruments for the writer, having a triangular base and three leveling-screws.

Mr. Lyman appears* to have misunderstood the writer's statement on this point. It does not imply that the first leveling-up is done by one hand, but simultaneously by both hands; after which, if any little displacement resulted, only one hand is required to readjust. No doubt a learner would take as much time in leveling with one system of screws as with the other; but, after the habit was acquired, the writer believes that preference would be given to a triangular leveling-base with three screws.

It is strange that some American instrument-makers continue the use of four leveling-screws, instead of generally introducing three, especially as the instruments employed in the U. S. Coast and Geodetic Survey (at least all those which the writer has examined) are constructed with three leveling-screws. The national geodetic engineers should be good judges in this matter.

Compass on Telescope.—As the writer has already remarked, he did not "adopt" the magnetic compass when he first placed it, in 1857, on top of a theodolite-telescope† similar to the one described by Mr. Scott (Fig. 17 of his paper‡); but he believes that he was the first who applied it to practical use in the position indicated. Mr. Lyman (speaking of another instrument) says§ that the magnetic compass is "incapable of use when the telescope is at all inclined." But it was never intended to be so used. When a theodolite is employed in a general underground survey, only a few magnetic bearings are required, unless for curiosity or to prove some scientific conclusion; and the places for these may be selected at the discretion of the

* *Trans.*, xxxi., 91.

† *Trans.*, xxix., 963, and xxxi., 54.

‡ *Trans.*, xxviii., 698.

§ *Trans.*, xxxi., 105.

surveyor. When this has been done, the circular compass is unshipped from the top of the telescope and packed away.

Generally speaking, one or more magnetic bearings are obtained from some of the lines along the level roads, or those almost level, where the telescope is not much inclined. Moreover, very little time is lost, in taking a few bearings upon a severely inclined plane, by bringing the telescope to a level position and allowing the needle to settle. If nothing more than the magnetic bearings were required in an underground survey, no surveyor would encumber himself with a theodolite. In no other way of attaching a compass to a theodolite can such a clear sight be obtained, when it is necessary to read a magnetic bearing at any point of the circle. What the writer found to be exceedingly convenient in 1857 he has not had reason to discard since; and, therefore, for the use indicated, he can recommend the plan with confidence.

Verniers upon the Needle.—The mounting of verniers upon the ends of a magnetic needle was effected many years ago in the construction of compasses for some nice scientific purposes, and occasionally a few persons have adopted the plan, with considerable success, for mine-surveying compasses. Naturally, it cannot be expected that such a fine and certain reading will be thus obtained as from the limb of a theodolite-circle, on account of the sensitiveness of the needle, the continuous oscillation of which, even when not appreciated by the eye, may be observed through a magnifying-glass. Nevertheless, a vernier-reading from the ends of the magnetic needle will be found much more accurate than when the same bearing is read as indicated by the rough point of the needle itself.

From the remarks of Mr. Lyman concerning the position of the magnetic compass mounted on Mr. Scott's instrument,* it appears that he would prefer to place it upon the horizontal vernier-circle, and between the standards supporting the telescope of a transit-theodolite. But that position would involve greater difficulty in reading a bearing at any part of the compass-circle, because the standards and other parts of the instrument would be obstacles to a clear view. One of the best English instruments, with a magnetic compass so placed, is that of Fig. 74†; but after much experience the writer preferred to

* *Trans.*, xxxi., 105; also xxix., 1009. † *Id.*, xxix., 962.

place the compass as shown in Fig. 148,* because it is open and free from obstacles, and offers every facility for reading the verniers attached to the ends of the needle.

One of the greatest advocates in England for the sole use of the miners' compass is Mr. Henderson, of Truro, Cornwall, who asserts that he has constantly employed the magnetic needle with a vernier attached to its northern end. In a recent discussion, some remarks having been made upon "coarse magnetic-needle readings," Mr. Henderson said:

"There is no reason for this appellation. A good needle, scientifically made, pivoted on a ruby, with a vernier attached to the north end, enabling the operator to read a bearing to, at least, 2 or 3 minutes, can be procured; and work of great accuracy could be effected through its use. It is the fault of the surveyor if he uses one of a coarse or common description."

Mr. Henderson declares that he has never employed in the mines of Cornwall any other instrument than a miners' dial, and, what is more important, that he has never committed an error.

Mr. Scott's Tachymeter.—The writer has already expressed himself upon this instrument, and, after a further examination of the diagrams and description of it, is quite convinced that Mr. Scott has conferred a great benefit upon all progressive mine-surveyors, not only in discussing the merits and demerits of various old and modern instruments, such as have been, and still are, employed in Europe and the United States, but also by indicating, among those he has described, the instruments best adapted for practical use. Without having actually experimented with Mr. Scott's new instrument, the writer believes it is the best yet constructed in North America for general surveying-purposes, and is also well-adapted for the particular and delicate operation of connecting underground workings with the surface by sighting down a shaft—which is the special use for which Mr. Scott has designed his auxiliary telescope. It is doubtful, however, whether the length of telescope and the size of object-glass he has chosen would be sufficient to command the deepest shafts.

In his further discussion, Mr. Lyman says, parenthetically, that "notwithstanding Mr. Hoskold's argument that sighting

* *Trans.*, xxxi., 52.

a telescope up a shaft gives the same angular result as sighting down it, the sight cannot be equally satisfactory if water be dripping abundantly upon the upturned object-glass." The reference given in his footnote (*ante*, p. 99) appears to refer to my second contribution (*ante*, p. 50), where the discussion refers to the observation of angles upon inclined planes, and not to "sighting a telescope up a shaft," which Mr. Lyman evidently means to be vertical.

The idea which Mr. Lyman intended to convey could not refer to the statement in my first contribution,* with reference to the use of the transit-theodolite (Fig. 74) for sighting up a shaft, for in it there is the clear statement that "in deep and wet shafts this plan was impracticable; but in shallow, dry pits, when the operation was performed on dark nights, fair success was obtained." This statement contains no intimation that up-sights and down-sights in a vertical shaft are "equally satisfactory."

On the contrary, if this is what Mr. Lyman had in his mind, the words "fair success" do not imply an unqualified recommendation of the method, which was, in fact, only the best that could be done at that time with the particular instrument (Fig. 74) in shallow and dry pits.

But the writer is convinced that the passage cited by Mr. Lyman refers to steep inclines, and not to vertical shafts. Nothing more was intended than an endeavor to show that Mr. Hulbert was in error in saying that on a certain inclination, which he indicated, no sight could be taken with the ordinary transit-telescope. The writer's proof that the thing could be done under the circumstances stated does not warrant Mr. Lyman's application of it to vertical sighting, *i.e.*, up or down a perpendicular pit or shaft. For inclined sights, practical mine-surveyors could, one would think, devise something that would prevent water from "dripping abundantly upon the upturned object-glass." Besides, it should be remembered that there are as many dry as there are wet mines, therefore the *pros* and *cons* are equal.

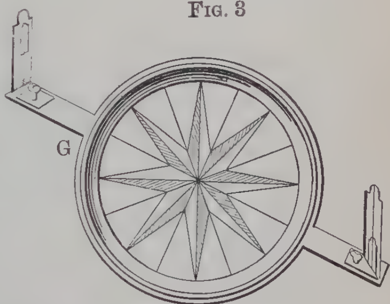
Mr. Scott's Paper.—Referring to the remarks made by Mr. Scott upon the old form of mine-surveying dial (Fig. 12),† the

---

* *Trans.*, xxix., 960, 961, and Fig. 74 on p. 962. † *Trans.*, xxviii., 692.

writer has found a much older example of a similar instrument (see Fig. 3) in the English translation of Bion, by Stone.* It is highly probable that other similar ones were made up to the time of Jones. The dial represented in Fig. 3 was 7 in. in diameter, and divided into 360 degrees upon a card, as is the practice to-day with compasses attached to the feet of large English celestial and terrestrial globes. The needle was suspended, as at present, under a glass cover, and Stone calls it a circumferentor. The German copy of Bion, dated 1713, is also a translation from the French original; but this dial (Fig. 3) does not occur in it—a strong inferential evidence that the instrument was not described in the French original, and is, consequently, an English invention, introduced into the English edition by Stone. Probably it received successive improvements. At all events, the divided card was abandoned; for Jones introduced a divided circle of metal, gave an independent motion to the instrument by means of a rack-and-pinion, and also placed inside the compass-box a vernier which read to 3 minutes of arc, and was used like a theodolite. The metal ring placed inside the compass-box and upon the upper thin base-plate (for there were two, one revolving upon the other), was provided with two sets of divisions, one on the inner edge, for needle-readings, and the other on the outer edge, for vernier-readings. The plane-sights revolved horizontally with one of the base-plates and vernier. This form of the miners' dial was then called a circumferentor, and is made to-day, under the same name, in precisely the same form.

FIG. 3



Magnetic Compass of Stone's Bion, 1723.

Sisson's Theodolite.—Since Mr. Scott wrote his paper, the writer has also discovered that Fig. 16 in that paper† is not "after the general style of Jonathan Sisson." Fig. 4 represents the original form of Sisson's theodolite, which was some-

---

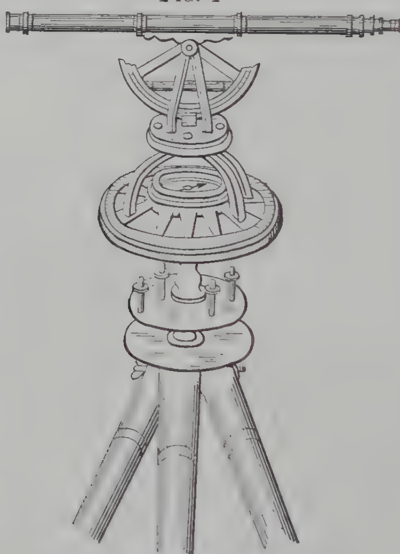
* Stone's English translation of Bion, London, 1723, p. 128.

† *Trans.*, xxviii., 696.

what peculiar in construction. This instrument is illustrated in an old English work,* and described as follows:

"For the more perfect understanding of what I would say on this head, it will be requisite that I give a description of one of the best sort of Theodolites ever yet invented for the use of a Surveyor in measuring and mapping made and contrived by Mr. Jonathan Sisson at the corner of Beaufort Buildings in the Strand; (a figure whereof is exhibited in the Map fronting the Titel-page of this Book). The Ball and Socket of this instrument are so contrived that by the help of four Screws placed at right angles to one another below the Centre, the whole is very rapidly fixed horizontal as well as steady; and thereby not liable to any Motion or Variation upon moving the Index. There is a double Sextant of Equal Radius to the Limb (with a Spirit Level fixed in it, and a telescope above it) that moves

FIG. 4



Sisson's Theodolite prior to 1727.

in a circle at Right Angles to the Index on the Limb, whereby the vertical Angles may be taken as readily as the horizontal, and at the same time; and so the hypotenusal Lines may be reduced to horizontal, which are those that should always be laid down in plotting any Survey.

"The head of the three-legged staff is of Brass, and not as liable to shake as the wooden ones. The Needle in the compass-box hangs on a Pin of tempered steel (twined and polished in a lath) in which it moves very freely; and the Limb is so curiously divided (by a new Method) that though there be three Indexes at 120° from each other, with Nonus's Divisions on them, to show the decimal Parts of a Degree; yet you shall perceive no Inequality in the Divisions on any part of the whole Circle.

* *The Duty and Office of a Land-Steward*, by E. Lawrence, Land Surveyor. 2d edition. London, 1732, pp. 133–5.

"There is also a Spring and Screw to the Index under the Telescope to fix it to any Degree of the Limb. The whole is nicely framed, very portable and well contrived for dispatch of Business."

The curious and novel method of dividing the limb of Sisson's theodolite, referred to in this quotation, could not have been done by Ramsden's engine (1773), and it is highly probable that it was done by Bird, a celebrated divider of instruments, who was born in 1709, and died in London in 1776, three years after Ramsden made his invention. To Bird is due "our first scientific mode of dividing astronomical instruments." He wrote a treatise upon methods of graduating instruments in 1767.

The writer has not yet discovered any instrument of the theodolite class filling up the interval from the time of Digges to that of Sisson.

It is interesting to note that when Sisson constructed his large mural arc (which in 1829 still remained in the Richmond Observatory), he made the slow-motion, or tangent-screw, which was attached to it, with a divided head, by means of which, in an observed angle, the additional number of seconds not indicated by the vernier could be determined.

The same plan was adopted by the celebrated optician, Bird, in his portable quadrant. At that period, the clamping and slow-motion screw-apparatus had a form similar to that of to-day, although less perfect; and if it had not been liable to get too much play from the wearing away of the parts, it is highly probable that the plan, afterwards so successfully employed, of measuring small angles by compound reading-microscopes (which appears to have been suggested by the Duke of Chaulnes, and afterwards adopted by Ramsden), might not have become necessary.*

At the present time, German theodolites with divided-head tangent-screws are used in various parts of South America, under the belief that this is a new invention, although it was introduced into England by Sisson more than 150 years ago.

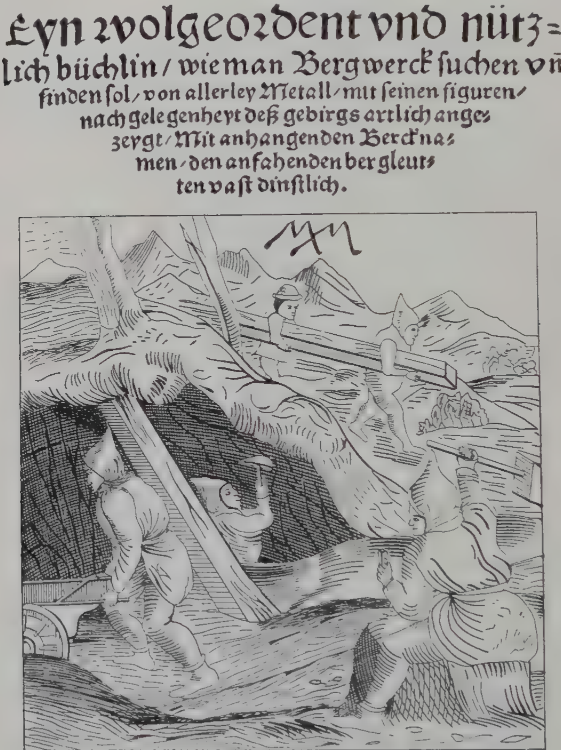
Books on Mining and Surveying.—The writer has not had the opportunity of examining either of the three copies known to

---

* Bird published his system of dividing one year before the Duke published an account of his new method of dividing, and of his micrometrical microscope.

exist of the first German work upon mines and mine-surveying, published about 1504–5, with later editions in 1515, etc.; but the Director of the Freiberg Mining Academy was good enough to obtain a photograph of the title-page, with the title of *Eyn wolgeordent und nützlich büchlin wie man Bergwerck suchen uñ finden sol*, etc.,* and as the first and succeeding editions of

Fig. 5.


Eyn wolgeordent vnd nütz=
lich büchlin / wie man Bergwerck suchen vñ
finden sol / von allerley Metall / mit seinen figuren /
nach gelegenheyt deß gebirgs artlich ange=
zeygt / Mit anhangenden Berckna=
men / den anfahenden bergleut=
ten vast dinstlich.

Title-Page of the Earliest Known German Work on Mining, 1515.

this book are exceedingly rare, a reproduction of the title-page may be of interest. Fig. 5 represents a copy from the edition of 1515. The two old dials, Figs. 141 and 142,† were also obtained from this edition.

* Secretary's Note.—The full translation of the title is as follows: *A well-arranged and useful little book: How Mines should be sought and found, of all kinds of metal; with its figures suitably indicated according to the circumstances of the country-rock. With appended mining terms, very serviceable to working miners.* The word *anfahenden* is a misprint for *anfahrenden—i.e.*, "going to" (the mine)—still the technical term among German miners for going underground to work.—R. W. R.

† *Trans.*, xxxi., 36, 37.

In an old Latin book in the possession of the writer,* many diagrams occur representing surveyors of that period taking altitudes, distances, depths, and other observations, by means of an astrolabe of ancient construction. One of the most curious and interesting of these is Fig. 6, in which an ancient surveyor is exhibited in the act of determining the depth to the water at the bottom of a pit, or well. He appears to have taken the diameter of the pit at 8 ft., and the altitude, or perpendicular of a right-angled triangle, was formed upon the depth as a base, which appears to have been 32 ft. It is probable that this interesting problem was invented by the author of the old book to illustrate the use of the instrument. It is, however, important as illustrating what progress has been made in surveying operations from 1504–5. The process indicated is partially involved in the principle applied by Bourns in 1842, with the difference that it was employed for a different object.

Thomas Stirrup. In 1655, Stirrup published an interesting work, *The Description and Use of the Universal Quadrant. By which is performed with great expedition, the whole Doctrine of Triangles, both Plain and Spherical, two several ways, with ease and exactness. Also the resolution of all such Propositions as are most useful in Astronomy, Navigation, Surveying and Dialling*, etc. The back of the instrument described is curiously constructed, consisting of three parts: a fixed square of brass with a circle inscribed within it, and upon and within the divisions of that circle another movable brass circle, made to move round a center-pin. The inner or movable circle had a series of meridian circles and parallels drawn upon it, as on a globe, and there was also an index-bar, made to move round and upon the movable brass circle; the movement of each being independent of the other. The front side of the instrument was also inclosed by a square with the arc of a quadrant marked upon it, the whole face being divided with series of parallel lines at right angles to one another, and apparently intended to represent the length of natural sines and cosines corresponding to the angles marked upon it. Vertical angles

---

* *Elucidatio Fabricæ Ususque Astrolabii Ioanne Stofterino Iustingensi* (1553), p. 173.

seem to have been taken by means of two plain sights, and a fine plumb-bob line marked the angle of elevation, as also the length

FIG. 6

Determining by means of an Astrolabe the Depth to the Water at the Bottom of a Pit or Well (1537), 1553.

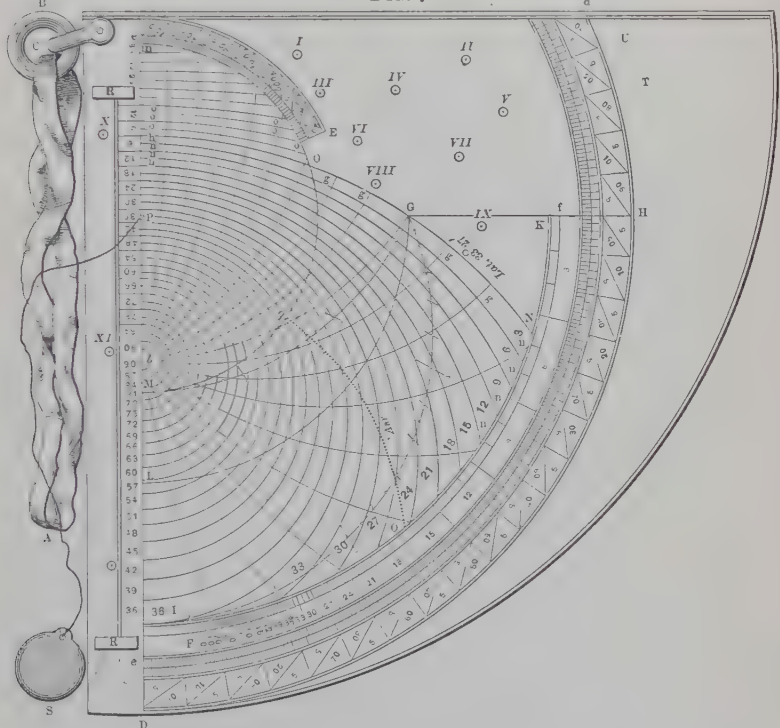
of the base and perpendicular corresponding to the angle. Stirrup very quaintly remarks:

"If you fit sights accordingly to the planisphere on the back-side (as I was intended to have showed, had not time called me away so fast) so as they move about with the Planisphere, the Horizon will show upon the limb the quantity of any angle taken in the field, as well as the Theodolite, Plain-table, Circumferentor or Peractor."

Referring to the contents of his third book and astronomical propositions, he says also:

"All of which I very well know, may more easily be performed by the canon of Sines, Tangents, and Logarithms, yet nothing so speedy as on the instrument;

FIG. 7



Quadrant of Ali Benash-Shihab, 1334.

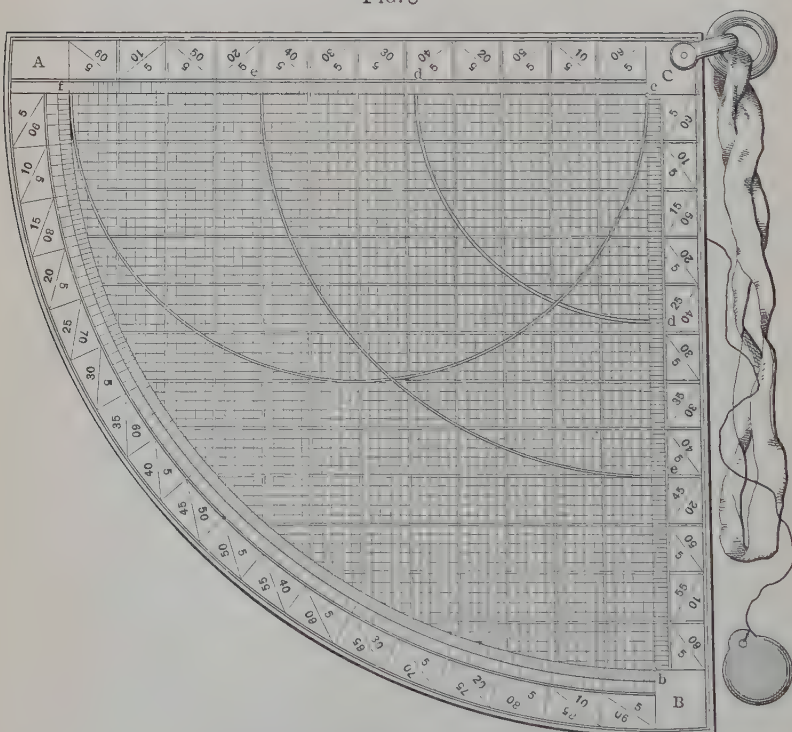
But for observation an instrument must be had wherewith (if thou likest it) thou art here fitted, both for observation and operation."

It will be observed that, in contradistinction to the circumferentor, Stirrup refers to the theodolite; the allusion could not, however, have been made to the instrument of Sisson (1731); it refers, probably, to one of the style of Digges's, or some improved form of it.

Sturmy also described a sinical quadrant in 1669. That de-

scribed by Stirrup is very similar to that constructed by Ali Benash-Shihab, in 1334. This extraordinary instrument is represented by Figs. 7 and 8. It was made of brass, inlaid with gold, silver and copper, and was, a few years prior to 1860, in the possession of Mr. Morley, and in perfect condition. One of the sides of this instrument (Fig. 7) had various circles engraved upon it, very complicated, and, as would appear, intended to be used for astronomical purposes. The opposite

FIG. 8



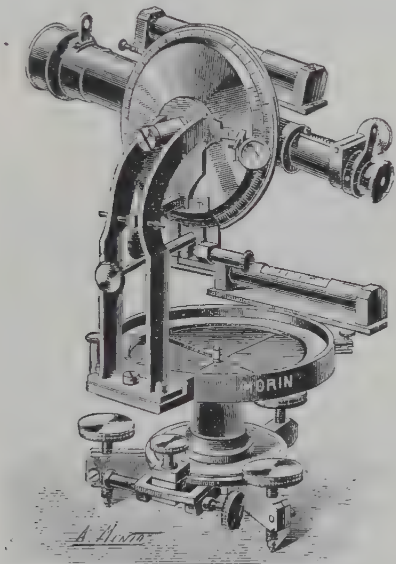
Quadrant of Ali Benash-Shihab, 1334.

side, or second face (Fig. 8), also had the form of a quadrant, the outside circles of which were divided into spaces of 5°, increasing to 90°, each way, by a double set of figures. There are two inner circles, one of which is divided to single degrees, and the other to 30′. Each side of the quadrant is also divided into spaces and figured from 5 to 60 degrees, and by an inner scale to 30 minutes. Corresponding to the angles and side-scales, the face of the quadrant is divided by 120 parallel lines,

with another series at right-angles; so that the instrument may be called a "quadrant of the canon," *i.e.*, representing the length of the natural sines and cosines, corresponding to the angles represented on the quadrant. In the instrument under notice, each fifth sine is inlaid with copper.*

The original description of this instrument is largely mixed with Arabic names and characters. Similar ones are also placed upon the instrument itself, rendering it difficult to be understood. No doubt this quadrant represents the fourth part of

FIG. 9



French Mine-Surveying Instrument.

the astrolabe as it was constructed in ancient times, and probably brought down from the time of the Assyrians.

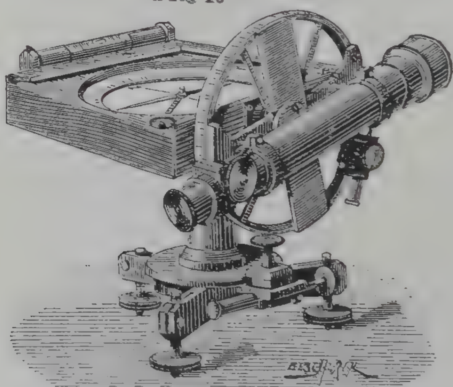
The writer now proposes to notice some of the more modern French and English surveying instruments.

French Instruments.—In Fig. 9 we have a fair representation of a comparatively modern form of a French mine-surveying instrument. It is an attempt to fit a telescope with a vernier, to revolve vertically around a vertical circle which appears to be attached to a single support or standard, placed on one side of the compass-box; the upper part of the standard being bent so that

* *Journ. Roy. Asiatic Soc.*, Part 2, vol. xvii., 1860, pp. 330–332.

the telescope is supposed to be suspended over the center of the instrument, and made to revolve vertically like a transit-theodolite telescope. Possibly it may be intended that this instrument shall supersede or replace the common type of French magnetic compasses, some of which have a telescope and vertical circle placed at the side, as in the case of Combes's, and various other models of *boussoles éclimétrès*. The best of these, represented in Fig. 10, is nothing more than a magnetic compass, placed in a square wooden box, with a vertical circle and telescope attached to one side, and a spirit-level on the top of the box at the opposite side; the whole being mounted on a triangular leveling-frame, with three leveling-screws, and clamp and tangent, to give a slow horizontal motion to the

FIG. 10



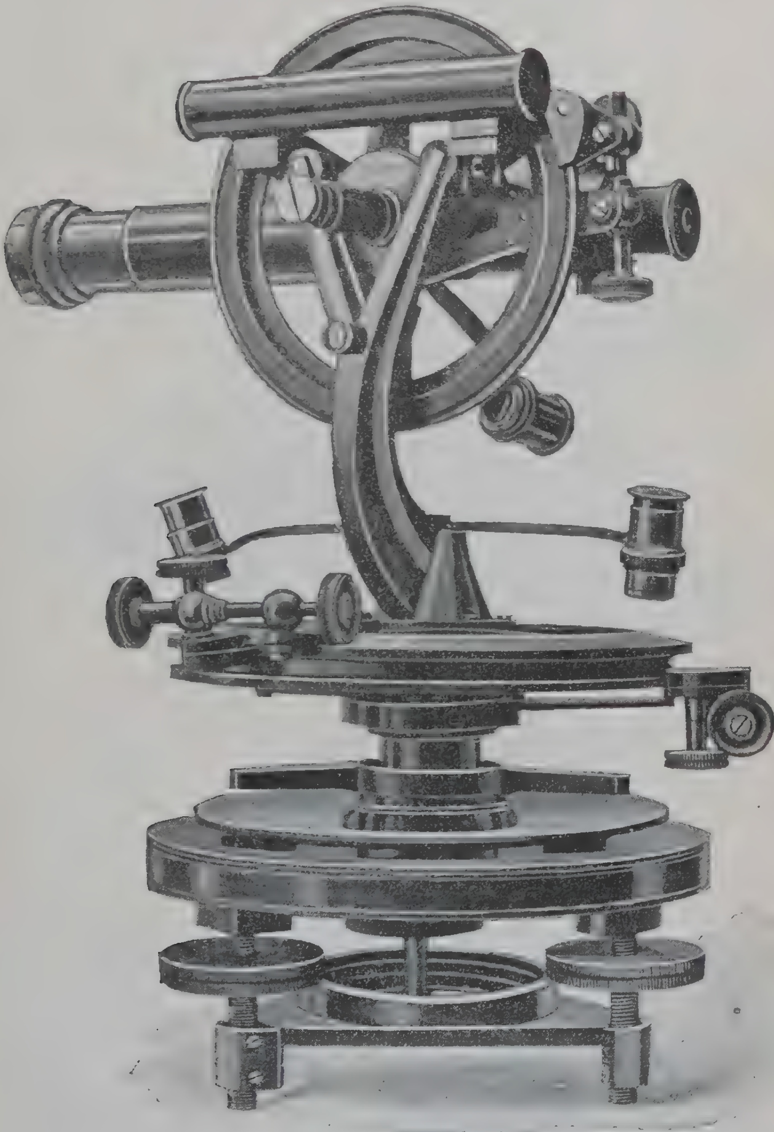
French Miners' Dial, with Telescope and Vertical Circle.

telescope. M. Morin constructs also other instruments of a similar class, mounted with two vertical arcs opposite one another instead of a complete vertical circle; also with a telescope, but without any vertical arc; and, again, with a long piece of wood, pierced, for sighting-purposes, with two longitudinal holes. All these instruments, except Figs. 9 and 10, and the one with two vertical arcs, are mounted upon a common form of ball-and-socket joint. The defects and inefficiency of these instruments for mine-surveying are too apparent to require any discussion.

English Instruments.—Fig. 11 represents an instrument introduced some years since by Telford. It has only a single tandard, upon which the vertical circle and the telescope are

supported. It will be observed that the single standard is curved from the central vertical axis, which, together with the

FIG. 11.

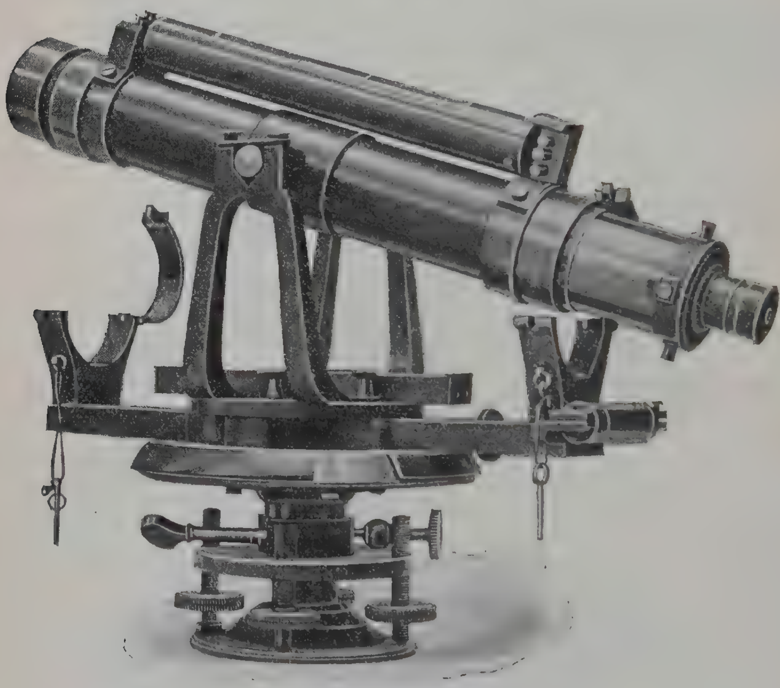


Telford's Theodolite.

thickness of the vertical circle, vernier-bar and semidiameter of the telescope, permits the telescope to revolve vertically

over the center of the instrument, like a transit-theodolite. The vertical circle and the horizontal axis upon which the telescope moves are clearly shown in the figure, as is also the mounting of the spirit-level at the back of the vertical circle. A pill-box level is inserted in a hole in the vernier horizontal circle. In a circular box below the horizontal divided circle is placed a traversing-plate, by means of which, and the clamping plates above, the theodolite could be moved in any direction

FIG. 12.



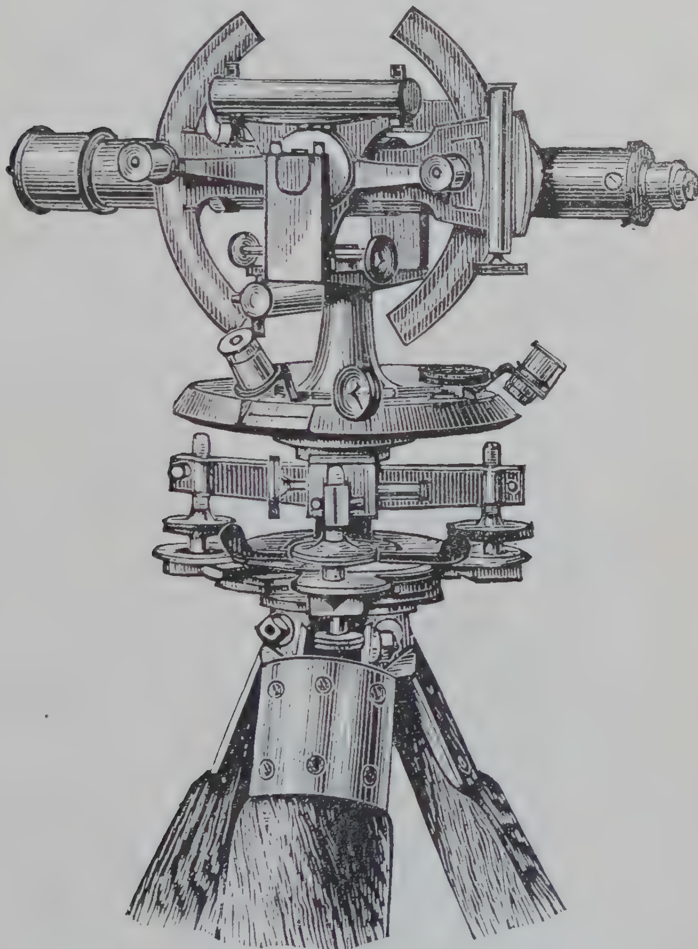
Adie's Theodolite.

horizontally for centering purposes, and clamped in position. This instrument had various defects, and never became popular; for which reason its construction has been discontinued.

Fig. 12 represents an instrument of the theodolite class constructed by Adie, and intended to be employed as an ordinary spirit-level (the telescope being placed upon a pair of low Y's attached to the ends of a long metal bar, fixed to the vernier-circle), and also as an ordinary theodolite, with the telescope raised upon a pair of higher standards, as exhibited in the fig-

ure. At the time of its construction it was a very useful instrument for railway-work, and suited those persons who did not wish to purchase and carry about two separate instruments. It had the deficiency of not being supplied with a vertical cir-

FIG. 13



Everest's Theodolite, with Improvements.

cle or semicircle, and, consequently, never became popular as a general surveying instrument.

Fig. 13 differs slightly from the original form of Col. Everest's theodolite, as introduced prior to 1838. The instrument here shown has received considerable improvement, principally in being divided upon a sloping or conical limb, instead

of upon a flat surface. The Indian and other engineers found the flat system of division inconvenient.

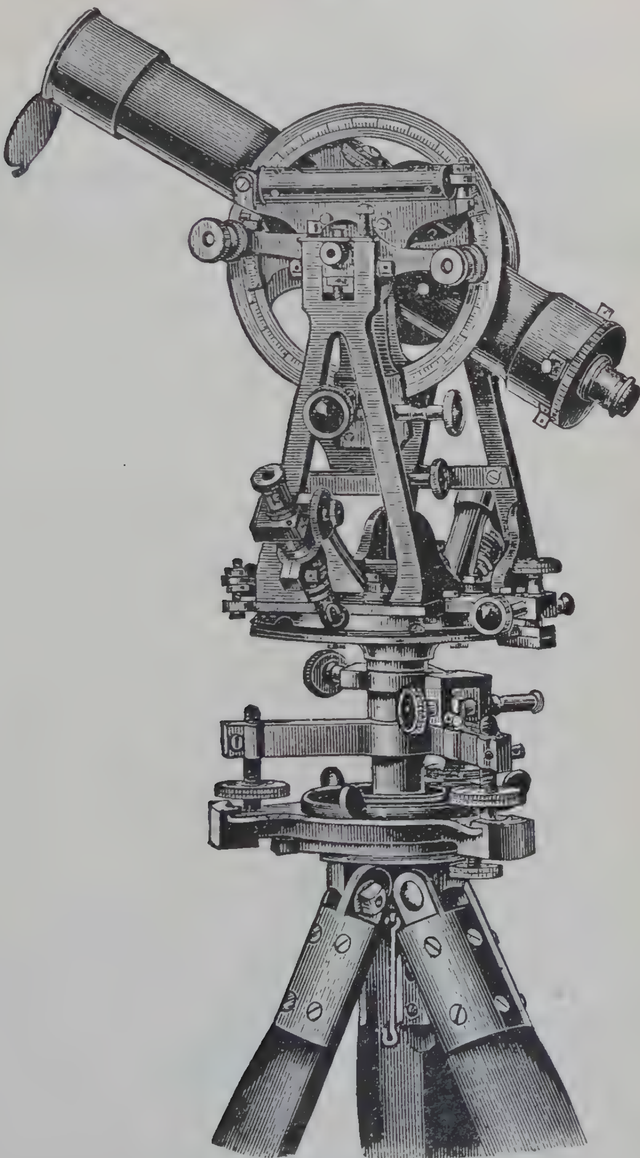
Troughton & Simms's centering apparatus has also been added to it, so that, at present, it is considered to be the best instrument for use in India and other hot climates. On account of its comparative lightness, as well as efficiency, it is especially useful for filling-in the details of a secondary series of triangles in a trigonometrical survey. It is constructed with three verniers to the horizontal circle, placed 120° apart. It has also means for reading double vertical angles within certain limits of arc, which, together with a powerful telescope, place the instrument in a superior class. It is not, however, adapted for observations in abrupt mountain regions, or for observing altitudes of high celestial objects; nor, so far as the knowledge of the writer goes, has it been employed in mine-surveying. No doubt this instrument could be still further improved by giving it higher standards, with more range of arc, and making the telescope to slide in the horizontal axis-socket, according to the plan which the writer has patented. In that case, however, it would no longer be identical with the instrument of Everest.

Transit Model.—Fig. 14 shows one of the best types of English transit-theodolites, 6 in. in diameter. It is what Troughton & Simms call their old form of construction; but this title only refers to the long telescope, with large object-glass and high standards. The eye-end of the telescope is made shorter than that of the objective, so that it revolves with the eye-end down. The vertical circle is read with verniers, and the horizontal circle with two micrometrical microscopes, placed opposite to each other, and read from about 10 to 5 seconds of arc, according to the use to which the instrument may be applied. It is mounted upon a triangular leveling-frame with three leveling-screws, and is supplied with an axis-level, lantern, and diagonal eye-piece; but it has no magnetic compass. The telescope is very powerful, and well adapted for long-line surveying and celestial observations.

Tacheometer.—Fig. 15 represents another instrument made by the same firm, and called a Tacheometer. Both the vertical and the horizontal circle are read by verniers. The telescope has great focal length with large object-glass, and the

eye-end of it is longer than that of the objective; consequently it revolves with the objective-end down. It is mounted in the

Fig. 14

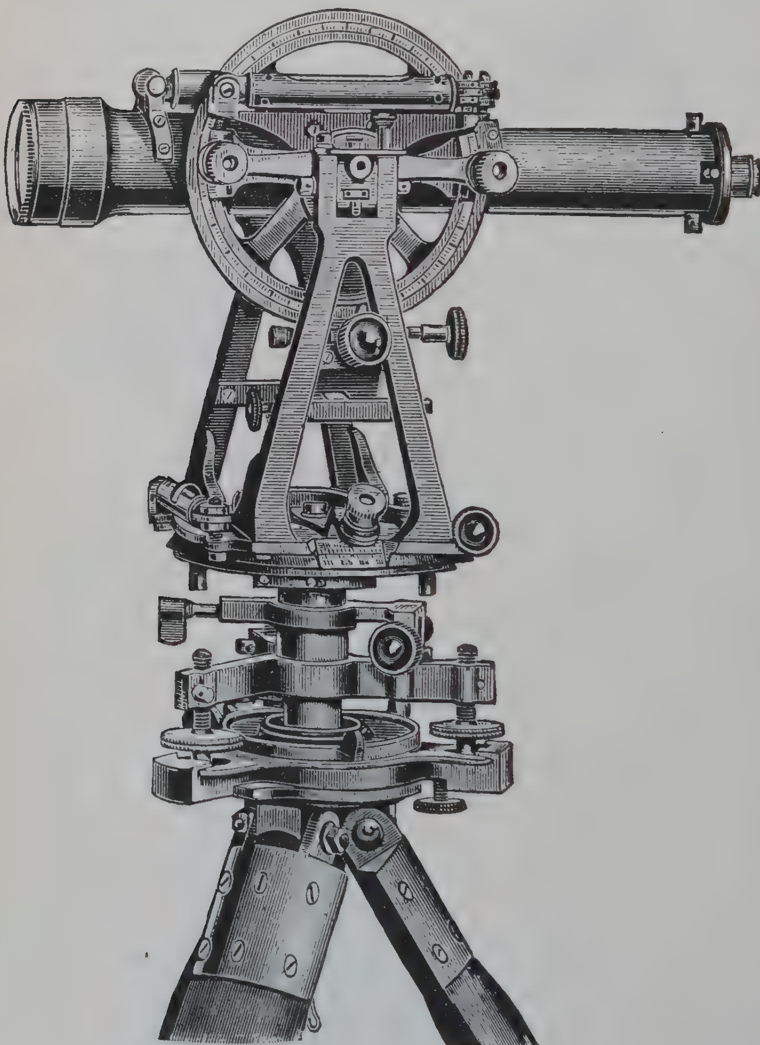


Troughton & Simms's Transit-Theodolite.

same manner as that shown in Fig. 14. Considering the comparatively small diameter of the circles of the two examples

selected, they are undoubtedly the best and most powerful for their size to be found in the English market. But the great height of the standards renders them top-heavy and objection-

FIG. 15



Troughton & Simms's Tacheometer.

able for common and quick surveying, especially underground. They are, however, excellent instruments for important and long-line surveys; for determining the length and direction of railway-tunnels to be driven through mountains from the two

ends (and probably, also, from the bottoms of shafts sunk at intermediate points); or for setting out the astronomical meridian by any of the known modes.

In recent years, however, Troughton & Simms have endeavored to remedy such defects in construction, as some consider long telescopes and high standards to be, by shortening the telescope and standards. In some cases an instrument 5 in. in diameter, divided to 20 seconds of arc, would have a telescope only 9.5 in. in length; but the length is varied, and may exceed this.

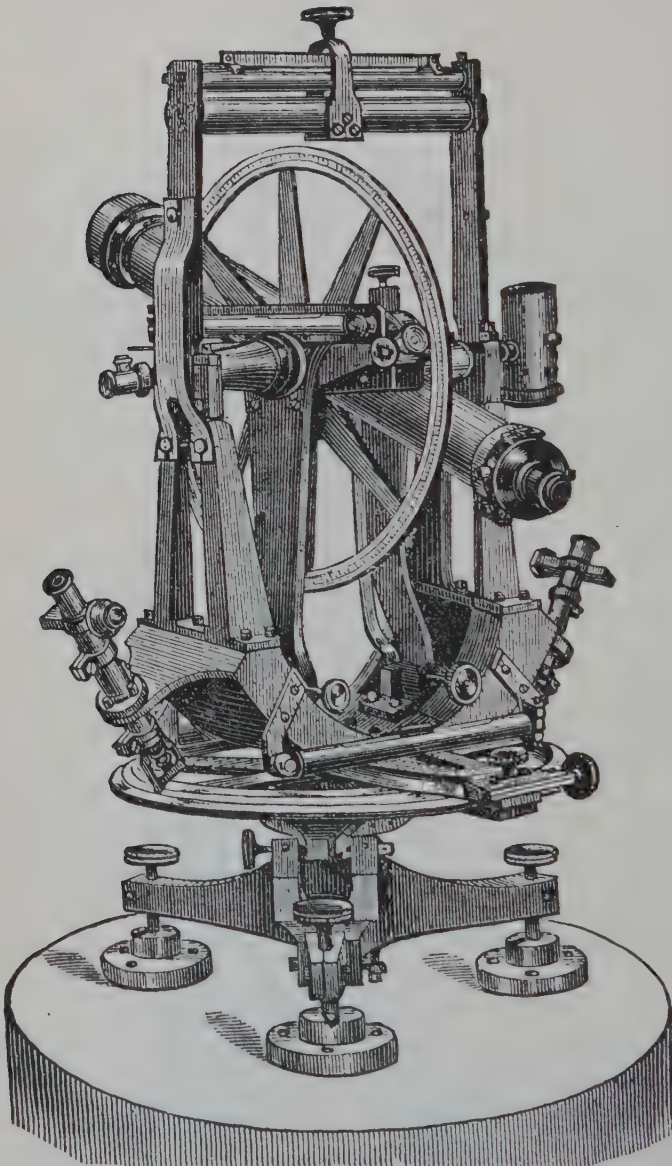
With a few exceptions, the English makers seem to be guided to a considerable extent by what is required in England (where excessively long survey-lines are never required), without taking foreign requirements into account. It must be confessed, however, that surface-surveying in all its branches has been carried to the highest perfection in England, the British colonies, and India.

Fig. 16 shows another exceedingly accurate instrument constructed by Troughton & Simms, the circles of which are generally from 12 to 15 in. in diameter, and, by means of powerful micrometrical microscopes, are made to read to 1 second of arc, and, by estimation, to one-half of a second. The telescope has considerable focal length with a large objective, and is mounted with a movable axis-level, lantern, etc. The standards are circular at the base, and, consequently, support the telescope in a very rigid manner. The entire instrument is fixed to a strong leveling-base with leveling-screws, and, as shown in the figure, may be conveniently used upon a pillar or a very strongly constructed stand. This class of instrument is finely constructed throughout, but is only intended to be employed at principal stations in a trigonometrical survey, or for taking the altitude of celestial objects, for which great power and exactness are required. This instrument is generally known as the alt-azimuth. It will, however, be seen that the divisions of the horizontal circle are placed on a beveled edge.

By varying the construction to suit conditions and circumstances, the same firm has made an instrument of a superior class, with circles 36 in. in diameter.

Hoskold's New Patent Civil and Mining Engineers' Transit-Theodolite.—This instrument will be described and discussed in a separate paper, already in the hands of the Secretary.

Fig. 16



Troughton & Simms's Alt-Azimuth.

Postscript.

The First Transit-Theodolites.—After much inquiry, the writer has not yet discovered who first made an engineers' transit-theodolite in England, or the date when it was made; but it is well

known that Halley had a transit-instrument constructed for the Greenwich Observatory soon after his appointment (about 1719). Ramsden made for Piazzi, in 1789, a transit-instrument with telescope and vertical circle. Small altitude- and azimuth-instruments were made by Troughton, who, in 1792, constructed for Count von Brühl a larger one of the same class, with circles 24 in. in diameter.

In the same year the Madras Observatory was erected, and was supplied with a 20-in. transit-instrument, and also an instrument with altitude- and azimuth-circles, 12 in. in diameter, both of which were made by Troughton. Wollaston had a transit-circle constructed as early as 1793. The astronomer, Pond, used an altitude- and azimuth-instrument constructed by Troughton several years prior to 1811, in which year Pond was appointed astronomer at Greenwich, where he immediately introduced alt-azimuth instruments. Cary, Jones, and others, also made transit-instruments prior to 1805; and a special class of smaller instruments of that type was made by Troughton some years prior to 1828. Cary also made, in 1802, for the Indian Trigonometrical Survey, a theodolite with circles 36 in. in diameter, which is believed to have had the form of a transit.

From these data we are obliged to conclude that the principle of the transit was employed in the construction of instruments in England at least as early as 1789, and there is evidence to show that it was even earlier. The one described as having existed in the Madras Observatory, with horizontal and vertical circles, 12 in. in diameter, and telescope, was to all intents and purposes a transit-theodolite of large size, and whether it was employed for terrestrial or celestial observations does not affect the question. This was as early as 1792. The transition from that instrument, and others described, to a common engineers' transit-theodolite, was slight; and, under the circumstances, the question between Messrs. Lyman and Scott as to whether Draper, in 1821, or Mr. Young, in 1831, was the first to construct such an instrument, has no practical importance.

All that can be claimed is that they both adopted, in the construction of instruments, a principle which had been followed in England for nearly a century.

A Crystalline Sulphide in Pig-Iron.

BY ANDREW A. BLAIR, PHILA., PA., AND PORTER W. SHIMER, EASTON, PA.

(Mexican Meeting, November,* 1901.)

It is now well known that certain pig-irons give a considerably smaller percentage of sulphur when determined by evolution-methods than when determined by oxidation-methods. The most striking examples of such irons are those made either wholly or in large part from New Jersey magnetites containing more or less titanium. It is never safe to use an evolution-method on such iron; for it is quite common that the sulphur result by evolution is only one-half or even one-third as great as that obtained by oxidation. For this reason, evolution-methods should be discarded, except in the analysis of pig-irons known to contain the sulphur in a state of combination from which it is evolved as sulphuretted hydrogen on treatment with hydrochloric acid.

A good example of an iron containing, in the residue, sulphur insoluble in hydrochloric acid having come to our attention, it was determined to try to isolate a suspected insoluble sulphide. A large piece of high-silicon gray-forge iron was accordingly selected as the most promising material to work on. This piece was dissolved slowly, through several months, in dilute hydrochloric acid, aided by the electric current, yielding a soft graphitic residue. The object of dissolving a mass of iron, instead of drillings, was to prevent the crushing, by the drill, of any insoluble crystalline compound that might be present. The first step in the preparation was to break up the graphitic material and put it through bolting-cloth of 157 meshes to the linear inch. This was done by crushing the mass under the fingers on the bolting-cloth fastened over the top of a beaker, while a stream of water from a wash-bottle washed the finer portions through the cloth. The suspended matter was allowed to settle. It was then transferred to a platinum

* In the pamphlet edition of this paper, the date was erroneously printed as February, instead of November, 1901.

dish and treated with hydrochloric acid to dissolve difficultly-soluble phosphide of iron, and afterwards with water containing a little hydrofluoric acid, to dissolve traces of silica. The material was then transferred to a beaker with water, filling it not more than one-fourth full. The graphitic material was well stirred; then the beaker was raised in the left hand, and, while being held at an angle of about 45°, it was gently and regularly rocked from side to side in such a way as to keep the lighter graphite in suspension, while the heavier particles settled into the lowest part of the beaker. It was soon noticed that a separation of brilliant golden scales was taking place. When it was judged that the separation was complete, the bulk of the water, with the suspended graphite, was poured into another beaker. The impure material at the bottom was washed into a smaller beaker; the separation was repeated in the same way, and the graphitic material was poured off. In this way several separations were made, obtaining a purer product of the brilliant scales each time. All the separated material was brought together into a beaker and treated again with hot hydrochloric acid of 1.12 sp. gr., to dissolve any remaining iron phosphide. The material was filtered off, washed and dried, and then stirred up with a dense solution of mercuric iodide in potassium iodide solution (Thoulet's solution) in a separatory-funnel. The graphite floated on this solution while the scales settled to the bottom. After this separation had been repeated several times, an apparently pure product was obtained. Under the microscope the material was found to consist of brilliant hexagonal scales of a light bronze color, with practically no admixture of graphite or other foreign matter. An analysis, made on the very limited amount of material available, resulted as follows:

	Per cent.
Titanium,	62.82
Iron,	1.82
Carbon,	9.82
Sulphur,	22.64
	97.10

Vanadium appears to be present in small amount; but there was no material left for its determination, nor for testing for

nitrogen, which may also possibly be present in such a compound. While we shall not speculate on a chemical formula for the new compound on the strength of this single analysis, made upon a very small sample of the material, we think that one most important and practical point has been determined, namely: that we have in this iron, and most probably in many other irons, at least such as are made in part from New Jersey magnetites, a crystallized sulphide of titanium, insoluble in hydrochloric acid, but soluble in nitric acid. Therefore we have a conclusive demonstration that no evolution-method can determine this sulphur, unless the insoluble residue is separately treated, in which case the evolution-method becomes slower and more troublesome that the oxidation-method, necessitating, in fact, an evolution-treatment *plus* an oxidation-treatment.

It may be contended that sulphur present, in forge- or foundry-iron, in the state of this insoluble sulphide would not have an injurious effect on the bar-iron or castings made from the iron. This does not necessarily follow, for when such irons are remelted, either alone or mixed with other irons, it is more than probable that the sulphur largely unites with the iron and manganese in the usual way, especially since the titanium, with which it is combined, is readily oxidized in part during the fusion of the iron.

Postscript.

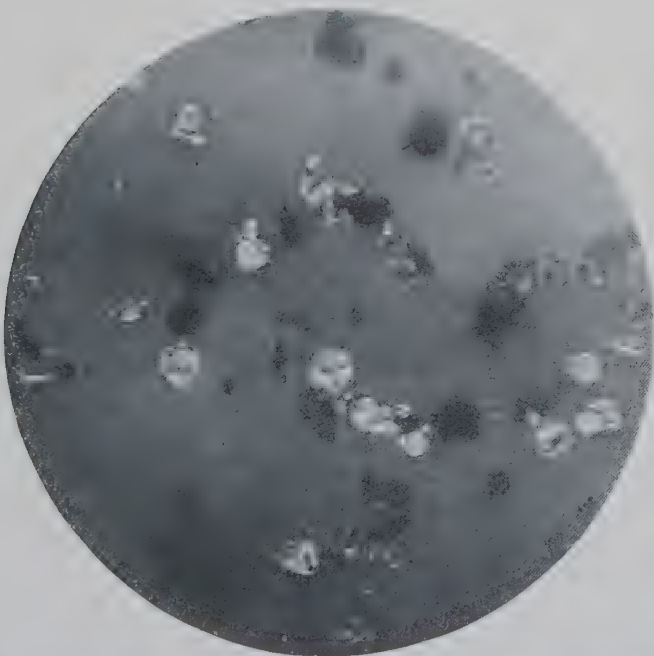
Secretary's Note.—The original manuscript of this paper was accompanied with a microscopic slide, showing a portion of the crystalline powder obtained in the experiment described. The particles, being opaque, could only be profitably studied under reflected light; and it did not seem practicable to produce from this slide an engraving which would so exhibit the crystalline sulphide as to add anything in the way of illustration or elucidation to the text. With the consent of the authors, therefore, the paper was published, in pamphlet form, without illustration.

Subsequently, however, the Secretary received from Mr. Frank Firmstone, Easton, Pa. (who had examined through the microscope a similar slide), a letter expressing his disappointment that no attempt had been made to reproduce this conclu-

sive ocular confirmation of the views of Messrs. Blair and Shimer. Mr. Firmstone added that he would be sorry to see this valuable new discovery suffer the fate of the discovery of the carbide of titanium, in which Mr. Shimer anticipated Moissan, but failed to receive the recognition which was his due.

In view of the earnest desire expressed by Mr. Firmstone, a fresh attempt was made to find some expert who would undertake the difficult problem of preparing from this slide a photo-

Fig. 1.



Micro-Photograph, Showing Crystals of Sulphide of Titanium Concentrated from Pig-Iron.

graph suitable for reproduction in "half-tone"; and the Secretary deems himself fortunate in having secured the services of Dr. James H. Stebbins, Jr., 80 Madison Ave., N. Y. City, the result of whose skillful manipulations is seen in the accompanying illustration. This special mention of him (made without his knowledge) is not only well deserved by him, but constitutes also a piece of useful information to members who may hereafter seek, in this line, experts capable of such delicate and difficult work.

For the benefit of those who are acquainted with modern photographic methods, I quote the following data, kindly furnished by Dr. Stebbins, concerning the details of the method by which he finally succeeded in achieving the measure of success shown in this engraving:

Objective, 0.5-in., Bausch and Lomb. *Eye-piece*, No. 2 Zeiss projection ocular. *Length of bellows*, 755 mm. from after-end of ocular. *Magnification*, 100 diameters. *Exposure* (found to be nearly correct), 3 min. *Color-screen*, dilute Zettnow solutions. *Dry Plates*, Cramer isochromic medium. *Illumination*, the Zeiss vertical illuminator, with Welsbach light. *Developer*, pyro-soda.—R. W. R.

The Treatment of Tailings by the Cyanide Process at the Athabasca Mine, near Nelson, British Columbia.

BY E. NELSON FELL, NELSON, B. C.

(Mexican Meeting, November, 1901.)

As this plant is the first ever erected in British Columbia for the treatment of tailings by the cyanide process, and as the ores of this mine are of a character not unusual among gold-ores of this Province, it is probable that a description of the principal features of the plant, and of the methods employed in its operation, may be interesting.

These works were designed after a careful study of the process, in a small experimental plant, for a period of six months. During this period ten percolation-tests on charges of tailings of 1100 lbs. each, eight percolation-tests on similar charges of concentrates, and twenty-six tests on concentrates in a revolving barrel, were made, besides laboratory-experiments.

The ore consists of a quartz gangue, containing a little lime and variable quantities of the sulphides of iron, lead and zinc. The following figures, giving the analyses of the ore before milling, and of the tailings after milling, which constituted the material to be cyanided, are based on the daily samples taken during February and March, 1901.

Analyses of Ore and Tailings.

	February.		March.	
	Ore. Per cent.	Tailings. Per cent.	Ore. Per cent.	Tailings. Per cent.
Zn, ...	1.93	0.91	1.92	0.91
Fe, ...	7.04	2.65	8.16	3.03
Pb, ...	1.63	0.20	1.24	0.21
CaO, ...	4.97	2.46	1.56	1.43
S, ...	5.99	1.71	6.02	1.75
Al_2O_3, ...	3.20	3.20	3.45	3.40
SiO_2, ...	74.20	85.00	74.30	86.10
	Oz. per ton.	Oz. per ton.	Oz. per ton.	Oz. per ton.
Au, ...	1.68	0.32	1.34	0.27
Ag, ...	1.32	0.38	1.34	trace.

The plant was designed to have a capacity of 30 tons per diem, with a 5-day period of treatment, including the charging and discharging of the leaching-tanks. Some changes which have been introduced, and which will be described later, have so reduced the period of treatment that the plant may now be considered to have a capacity of 50 tons per diem.

It is located on a steep hillside, and Figs. 1 and 2, showing the plan and side elevation, will explain its general arrangement.

At every step of the process, except the pumping of the spent solution from the sumps to the solution-tanks, the materials are moved by gravity. In order to secure this result large excavations had to be made in difficult ground, and heavy masonry had to be provided for retaining-walls and tank-foundations; the total excavation being about 10,000, and the aggregate of granite masonry about 1250 cubic yards. The cost of this work was great, and the total cost of the plant amounted to $31,096.79. Every effort was used to secure solidity of construction, and nothing but good material and workmanship was employed throughout.

The plant was located to receive the tailings direct from the mill, in two distributing-tanks, 14 ft. in diameter and 10 ft. in height. The tanks are fitted with annular launders around the rim and are filled with water before the admission of the tailings; the overflow is carried off in the annular launders, and thence in iron pipes to the waste-launder under the leaching-vats.

In order to control the proportion of slimes allowed to escape, a slimes-arrester is provided. This consists of a sheet

of iron, 10 in. wide, fitted inside each tank, about 1 in. from the staves, extending all the way round, and held in position by 8 iron brackets. This sheet is arranged so that it can be raised entirely above the level of the tank, or lowered and im-

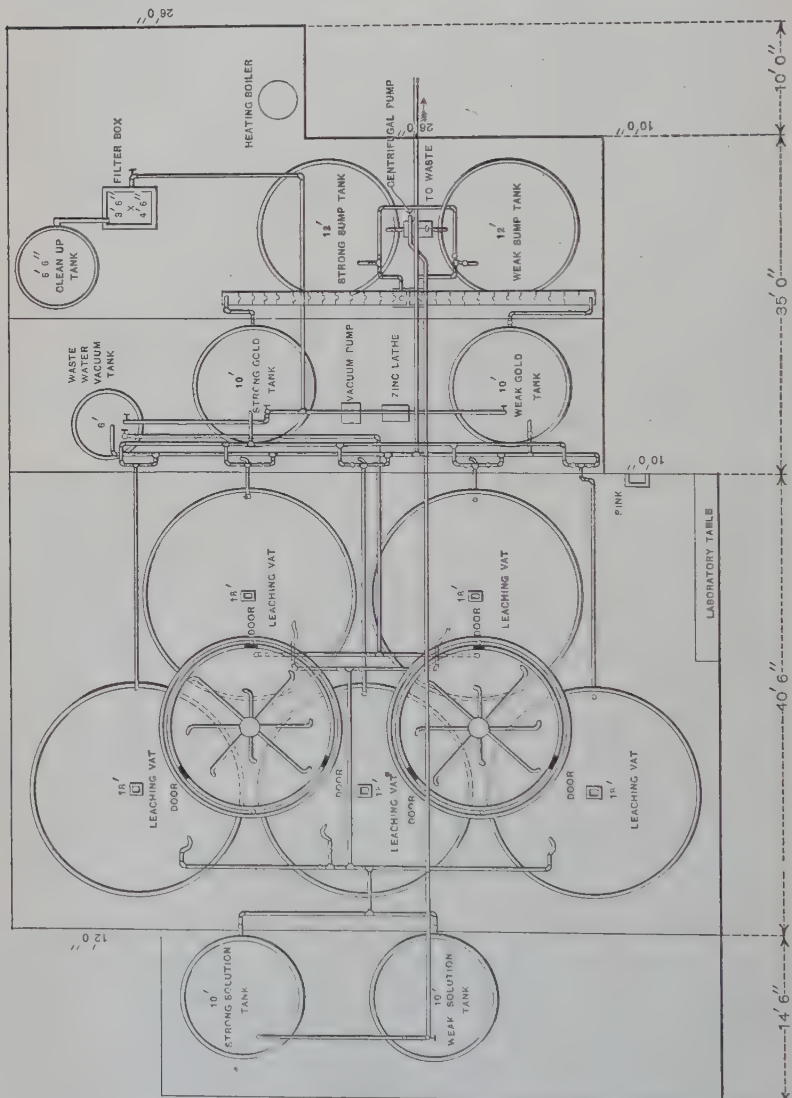


FIG. 1.

mersed until the upper edge is but slightly above the level of the water. In this position it is most effectual in arresting the outflow of slimes. The exact position of the sheet can be regulated to suit the character of the ore under treatment.

The tailings are distributed in these tanks by eight-arm distributors, working automatically. The tanks are fitted with filters and are connected, beneath the filter, with the waste-water receiver, which is in turn connected with the vacuum-pump. The cloth filters are protected by perforated boards against injury in shoveling out the tailings. When the tanks are full, the supernatant water is siphoned off, and connection is then made with the waste-water vacuum-tank for about twelve hours. At the end of this time the tailings are so nearly dry that a shovelful thrown into the vat below breaks up into a loose pile of sand. (The importance of this fact will be shown later.)

The distributor-tanks are placed over the leaching-tanks, on a frame partly of steel and partly of timber, in such a way that each tank can be discharged by three side-doors into any one of three of the leaching-tanks. Our usual practice has been to accumulate about 35 tons in a distributor-tank at one time; after drying, these can be discharged by shoveling at a cost of about 8 cents per ton.

The leaching-vats are five in number, arranged under the distributor-tanks, as described above, and shown in Fig. 1. They are 18 ft. in diameter and 4 ft. in height, are fitted with cloth filters and center discharge-doors, rectangular in shape, tightly closed up by bolts, and removable from the inside. Around the door-frame is a wooden frame to which the filter-cloth is attached; and, before the sands are admitted, a wooden cover is fitted over the iron door, having a pyramidal top to facilitate the current of the solution. The outlet-pipe for the solution connects with the bottom of the vat and runs either to (1) the strong gold tank; (2) the weak gold tank; (3) the waste-water vacuum-tank; or (4) directly to waste. The pipe-connections are such that any or all of the leaching-vats can drain through any or all of these channels simultaneously and independently. This is a very important provision for saving of time in the operation of the plant. Both solution and water are admitted to these tanks on top of the sands, and distributed through a floating box with perforated sides. This method of admission was found to be easier and more effective, and to give better results, than the plan of admitting the solution under the filter-bottom. The spent sands are removed by being

sluiced out through the center discharge-door—an operation which requires about 3 to 4 hours. We employ a hose with 1-inch nozzle, under an effective head of about 200 ft.

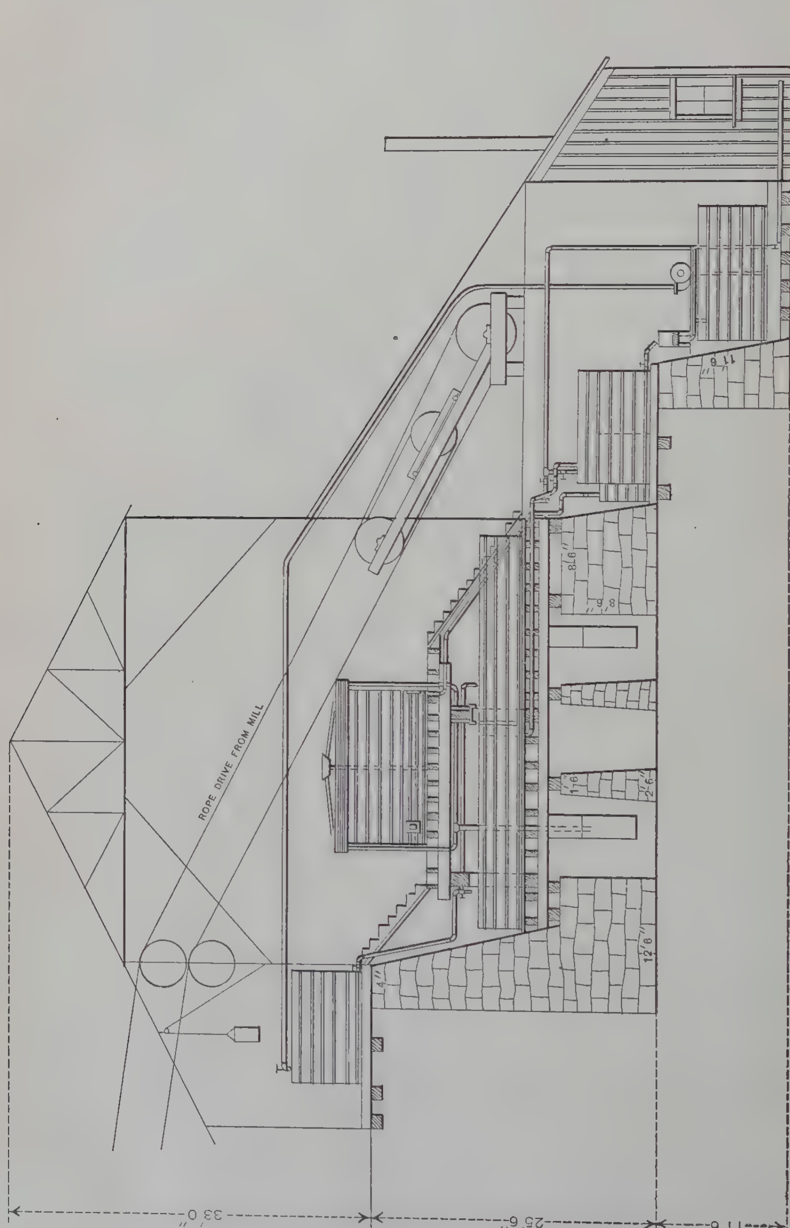


Fig. 2.

The gold-tanks are two in number, 10 ft. in diameter and 6 ft. in height, fitted with heads and connected with the vacuum-pump. In practice we seldom use this connection,

except at the end of the leaching-process, as the pump has a tendency to cause the sands to pack in the leaching-vats and to interfere with percolation.

From the gold-tanks the solution is run to the zinc-boxes, which are arranged in two series of twelve each. Each is a square movable iron box, with a capacity of one cubic foot of zinc-shavings; and each is independent of the other boxes. Below the zinc-boxes are two sump-tanks 12 ft. in diameter and 6 ft. in height. The solutions from either series of zinc-boxes can be drained into either sump, independently of the other, or can be drained to waste. Above the sumps is placed the centrifugal pump which forces the solution back to the solution-tanks—two in number, 10 ft. in diameter and 6 ft. high. The solution can be pumped from either sump-tank to either solution-tank.

The solution is made up to the required strength in the strong tank by placing the requisite quantity of cyanide in an iron basket, having sides of wire netting, and lowering the basket into the solution. The cyanide is entirely dissolved in this manner in about one hour. We quickly abandoned the plan of making up a large amount of strong solution in a stock-tank, as we found that the loss by decomposition was heavy.

The work done in the plant has been of two kinds: (1) the treatment of tailings direct from the mill (from February 18th to May 10th); and (2) the treatment of accumulated tailings (from May 10th to July 30th). The first group will be hereinafter referred to as "mill-tailings," and the second as "dam-tailings." Both groups were from the same mill and the same class of ore.

During the first period 841 tons of mill-tailings, and during the second period 1582.4 tons of dam-tailings, were treated, making a total of 2423.4 tons. At the end of the second period the entire contents of the zinc-boxes were cleaned up. The tonnage was estimated, by considering 23 cubic ft. of settled sands to be equal to one ton. This figure was first arrived at after careful measurements, but we realized that it was only approximate. The actual value of bullion recovered was $17,-179.77, while the amount which should have been recovered (estimating the tonnage as above, and the recovery as the differ-

ence in the assay-value of the tailings before and after treatment) is $20,083.74. In considering this discrepancy, it must be remembered that, at the commencement, the plant was quite new, and some time elapsed before the plant was running smoothly, leaks were stopped, and the various stages of the work were brought up to an efficient condition.

The average value of the mill-tailings was, before treatment, $5.28, and after treatment, $1.34 per ton—a recovery of 75 per cent. The average value of the dam-tailings was, before treatment, $10.83, and after treatment $2.17 per ton—a recovery of 80 per cent.

In considering the percentage of recovery in the case of the mill-tailings, the question of the conditions under which these tailings were deposited becomes very important. Before the filters were introduced into the settling-tanks, the value of the tailings was $6.00 per ton before treatment and $1.74 after treatment, or a recovery of 71 per cent. After the filters were introduced, the value of the tailings before treatment was $4.20, and after treatment 54 cents per ton, giving a recovery of 87 per cent. The figures are averages; but to emphasize this point further, I herewith give the assays of the last seven charges of mill-tailings treated at a time when the plant was running smoothly.

Lot.	Before Treatment. Per ton.	After Treatment. Per ton.
21,	$6.20	$0.21
22,	3.10	0.42
23,	2.48	0.21
24,	1.65	0.21
25,	2.27	0.21
26,	3.51	0.21
27,	4.96	0.21

This exhibit shows that, under this system, we were able to extract practically all the gold-values, even from tailings containing fairly high values at the start. I attribute this satisfactory improvement principally to the improved physical condition of the sands, due to the introduction of the filters in the settling-tanks.

Time of Treatment.—Before placing the filters in the distributing-tanks and obtaining the sands in a desirable condition, the average time occupied on each charge was 5 days 14 hours; after the change was made as above, the time occupied in treat-

ing 62 charges was 3906 hours, or an average time of 2 days 15 hours. The results of this important saving of time were far-reaching; the capacity of the plant was nearly doubled; the percentage of extraction was improved (by improved percolation); and less solution was necessary, involving less decomposition and consumption of both cyanide and zinc.

Consumption of Material.—During the periods under consideration, 2423 tons of tailings were treated, with a total consumption of 4977 lbs. of cyanide, costing $1360.65, and 950 lbs. of zinc, costing (uncut) $123.50. The cost of cutting is included in the regular wages of the plant. These figures show that 2.05 lbs. of cyanide, costing 54 cents, and 0.39 lbs. of zinc, costing 5.07 cents, were consumed per ton of tailings treated. Owing to various difficulties met with at the start, these figures do not exhibit what was being done when the process was running smoothly, and what can be relied upon in the future. During the month of July our consumption on tailings of the assay-value of about $10 per ton in gold was 1.25 lbs. of cyanide, costing 35 cents, and 0.25 lb. of zinc, costing 3.25 cents, making a total of 38.25 cents per ton. By careful and systematic work I believe an improvement on these figures might be realized.

General Working-Costs.—The following table exhibits, in column 1, the actual working-costs incurred in treating 2423 tons from February to August. In column 2 are shown the costs which, from our past experience, I believe we can confidently anticipate when the plant is in regular working-order and treating 40 tons per diem, which is a very moderate estimate of its capacity.

Actual and Estimated Costs.

	(1) Cents per ton.	(2) Cents per ton.
Foreman,	28.8	9.7
Assistants,	62.6	27.7
Assaying,	16.5	5.5
Total wages,	107.9	42.9
Cyanide,	54.0	35.0
Zinc,	5.0	3.0
Sulphuric acid,	4.6	4.0
Assay and refinery,	12.0	5.0
Fuel and sundries,	5.3	2.0
	80.9	49.0
Total,	$1.88	$0.92

Precipitation in the Zinc-Boxes.—For this purpose two series, each of 12 individual sheet-iron boxes, were used, with zinc-shavings as the precipitating material. The shavings were cut on a Hampton zinc-lathe, which proved satisfactory, with little waste of zinc. The precipitation was very perfect, even when the solution was allowed to run as rapidly as possible. In all of the numerous assays which we took from the lowest of the zinc-boxes, we never once found gold of a greater value than 21 cents per ton of solution, and usually found only faint traces. When we commenced working, we kept the strong and weak solutions in separate gold-tanks; but we found that when the weak solution was below 0.05 per cent. in strength, the precipitation was imperfect, and, on the other hand, when the strong solution was over 0.15 per cent., the consumption of zinc was excessive. We, therefore, partially mixed the solutions, so that the solution in the strong gold-tank should run about 0.10 or 0.12 per cent., and the solution in the weak gold-tank from 0.08 to 0.10 per cent. in cyanide. In this manner a perfect precipitation was obtained, with a much reduced consumption of zinc and cyanide in the zinc-boxes, and the strength of the solution in the strong sump-tank was maintained at about 0.08 and in the weak sump-tank at about 0.06 per cent. The solutions were thus kept at convenient strength for use as weak washes in the leaching-vats, and no waste of solution was incurred. During the passage of the solution through the zinc-boxes a heavy deposition of carbonate of lime takes place.

Clean-Up.—Once a month the zinc-boxes were removed one by one to the chamber in which was placed the acid-tank, 6 ft. 6 in. in diameter and 2 ft. 6 in. high. The zinc-boxes were thoroughly cleaned of slimes in this tank, and as much of the zinc was replaced as was thought desirable. The slimes were then settled with alum for 12 hours, and the water was siphoned off into a settling-tank. Hot water was then added, with sufficient acid to dissolve the zinc thoroughly. The liquor was then drained off through a filter-box connected with the vacuum-pump. The filter-material consisted of two woolen blankets and one canton-flannel sheet, firmly held in place by wooden cleats, and one canton-flannel filter, the sides of which came over the top of the box, loosely tacked in place. The

slimes were then thoroughly washed with hot water and the washings were drained off through the filter-box. The slimes were then washed into the filter, drained dry, and removed bodily in the cloth; and the whole was dried on a pan fitted with a hood. The product was melted with an excess of silica in a graphite pot, and the resultant slag was melted with litharge and the lead was cupelled. The bar obtained by this process averaged about as follows: gold, 548; silver, 294; base metals, 158 thousandths.

Method of Treatment.—After repeated experiments we adopted the following as our standard method of treatment:

The strong-solution tank was filled from the sump and made up to the strength of 0.24 per cent. cyanide. This tank contained about 12.5 tons of solution. The charge to be treated consisted of about 35 tons of tailings. About 7 tons of solution was admitted onto the tailings. This quantity was sufficient to saturate the tailings and to allow the solution to stand about 6 in. deep on the top. They were allowed to soak thus for 4 hours. The outlet-cock was then opened and the solution was drained into one of the gold-tanks. The draining process occupied about half an hour. As the last of the solution was draining off, a sample was taken to be assayed for both gold and cyanide. The rest of the solution (about 5.5 tons) from the strong tank was then admitted, standing about 6 in. deep on the tailings, and they were allowed to soak for 8 hours, after which the solution was drained off and sampled as before. In the meantime, the weak-solution tank had been filled with solution from the strong-sump, running about 0.08 in cyanide. This weak solution was then admitted (as required) to the tailings and the outlet-cock from the latter left open. In this manner the solution drained through rapidly, fresh solution being added whenever the surface of the tailings began to appear above the solution in the leaching-vat. When the last of the solution from the solution-tank had been admitted, the outlet-cock of the leaching-vat was closed. After the lapse of 8 hours the cock was opened, and the solution drained off and sampled as before. In the meantime the solution-tank had been again filled, but this time with solution from the weak-sump, running about 0.06 in cyanide. This

tankful was then admitted to the tailings and continuously drained off, and a second tankful from the weak-sump was drained through the tailings in a similar manner; during which process samples were taken at intervals, to be assayed for cyanide and gold. A water-wash was then admitted and drained through continuously, until the solution coming off gave not more than 0.06 in cyanide after repeated samplings, some of which were also reserved for gold. The process was then declared closed. So regular was the process in operation that, during many months of working, we neither accumulated solution, nor found it necessary to throw away solution, except what remained in the tank at the time the process was declared closed. This remainder contained only minute quantities of gold. The resultant solutions in the sump were so uniform in character that we could, in practice, regularly add to one tankful of solution, pumped direct from the strong sump, 50 pounds of cyanide, to bring it up to our standard grade of 0.24 per cent.

The cyanide contents were determined by the nitrate of silver test. The tests for strength of cyanide and the assays of the solutions for gold corresponded so regularly that the foreman in charge of the plant could estimate with accuracy and certainty the gold-contents of the solutions during the various stages of the operations. The record of the gold-assays, however, gave the data from which these estimations could be intelligently drawn, and from which small changes were suggested from time to time.

In practice this programme had to be modified more or less, in order to harmonize with the other branches of the reduction-works and the character of the sands under treatment. The following description shows the actual details of treatment, and the results obtained from the treatment of Lot 59, which was a fair average of the process:

June 26th, at noon, turned on strong solution (0.24 per cent.) until same stood 6 in. deep on the sands; allowed to stand 4 hours. At 4 P.M. opened outlet-cock and allowed solution to run into gold-tanks; at 4.30 P.M., as the last of the solution was passing off, took sample, which assayed "nothing" in cyanide and $9.30 in gold. Closed outlet-cock, admitted fresh charge

of strong solution, and allowed to stand 8 hours. At 12.30 (midnight), June 27th, opened outlet-cock, and at 1 A.M. took sample, as before, which assayed 0.06 cyanide and $28.94 in gold. At 1 A.M. turned on weak solution (0.08 cyanide), allowing same to drain through without interruption till 4 A.M. Sample at 4 A.M. assayed 0.10 cyanide and $8.08 in gold. Shut off outlet-cock and allowed solution to stand until 1.30 P.M. Opened outlet-cock and admitted fresh solution (0.06 cyanide) and allowed same to run through, admitting fresh solution as required till 12.30 (midnight), June 28th. Sample taken at 10 P.M. assayed 0.07 cyanide and $0.62 in gold. Closed outlet-clock and allowed to stand until 5 A.M. Opened outlet-cock at 5 A.M. and allowed fresh solution to run through until 11 A.M. Sample taken at 6 A.M. ran 0.06 cyanide and $0.42 in gold; and sample taken at 11 A.M. ran 0.6 cyanide and $0.21 in gold. At 11 A.M. turned in water-wash till 2 P.M. Sample taken at 12.30 P.M. ran 0.06 cyanide and $0.21 in gold; and sample taken at 2 P.M. ran 0.06 cyanide and $0.21 in gold. At this point the process was declared finished; the wash was drained to waste; and the tailings were discharged.

Assay of the tailings before treatment gave $13.02, and after treatment $2.07 in gold. Percentage of recovery, 84.1. Time occupied, 2 days 2.5 hours.

The reason why the process was apparently unduly prolonged at the close was to avoid any possible loss which might occur by any such sudden variations as occasionally took place, at the close of the operations, in the value of the solution. Moreover, as long as the solution was not being unduly accumulated, there was no advantage in allowing any values, however small, to run to waste.

It is worthy of note that the first sample taken would usually fail to show any trace of cyanide by the nitrate of silver test, while often assaying notable quantities in gold. The solutions were saved from the commencement, as the solution of the gold seemed to take place immediately. No preliminary treatment with lime was used in the process, as we never found any evidence of acidity, either positive or latent, in the tailings.

The general conclusion which I would draw from the above is, that the process is likely to prove very valuable for the treat-

ment of ore of this class, which is a very common class to be found in this country. I have presented the above figures exactly as they occurred; and in my estimated averages the general results have suffered seriously from certain individual failures, the causes of which we well understand, and which are likely to occur when a new plant is started. All of the factors of success are present. The gold is dissolved very rapidly; the precipitation is perfect; the consumption of cyanide and zinc is small; and the time required is short.

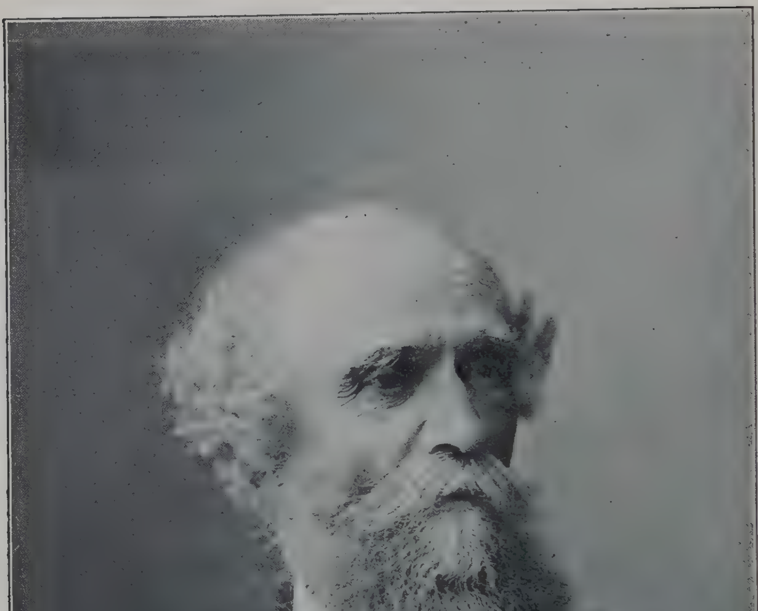
We have also carried out a series of experiments on the treatment of the concentrates from the mill, in a revolving barrel. The result of these has been so satisfactory that I believe the process would be successful on a working scale.

The following figures are the result of the last six runs which we made:

Dry Weight of Concentrates. Lbs.	Gold before Treatment. Oz. per ton.	Gold after Treatment. Oz. per ton.	Extraction. Per cent.	Strength of Solution. Per cent.	Loss of Cyanide. Lbs.	Duration of Treatment. Hours.
40, . .	7.58	.20	97.4	1	6.20	24
40, . .	5.26	.76	85.5	1	8.10	24
40, . .	4.74	.42	91.1	1	7.80	24
40, . .	2.78	.14	94.9	1	9.75	24
40, . .	4.60	.36	92.2	1.25	6.40	24
40, . .	3.92	.12	96.9	1	6.15	24

I infer that a recovery of at least 90 (and probably 92 or 93) per cent. of the gold values could be insured at a cost for cyanide of about $2.15 per ton. These figures refer only to the recovery of gold; but in our case, and in the case of other ores in this district, gold (and a trifling quantity of silver) is the only valuable material in the concentrates. When lead or other valuable products form an important item in the value of concentrates, this process would not be applicable.

I wish to acknowledge my indebtedness in the preparation of this paper to Messrs. H. W. Mussen, engineer, F. Vans Agnew, assayer, and A. Constans, foreman, all of whom furnished valuable information in connection therewith.



Joseph LeConte

Biographical Notice of Joseph Le Conte.

BY S. B. CHRISTY, UNIVERSITY OF CALIFORNIA, BERKELEY, CAL.

(Mexican Meeting, November, 1901.)

In the death of Joseph Le Conte, at Yosemite, Cal., on July 6, 1901, the Institute has lost one of its most distinguished honorary members, and the University of California its most beloved professor.

The South has produced many distinguished men. In the law, in politics, and in war, they have made their mark, and we are all proud of their records. But in science not so many have achieved distinction. The Le Conte family is thus the more remarkable, in that it has produced three men of eminence in that field, while there are descendants of promise yet to be heard from.

It is always interesting to trace the influences that go to make a great life; and in this case I am able to draw upon an abundance of material in the manuscript autobiography which Prof. Le Conte completed shortly before his death. Through the kindness of Mrs. Le Conte, I am permitted to make such extracts as may be needed to give a glimpse of his remarkable life and character. This autobiography, together with other unpublished notes and sketches of his experiences during the Civil War, covers nearly 600 closely-written pages, and is one of the most fascinating stories I have ever read. It is to be hoped that it will be published entire; for, while it is written with all the frankness of the *Confessions* of Rousseau, it depicts a noble character without a trace of morbid self-consciousness, breathes a high philosophic spirit, and is enlivened with a fine sense of humor.

It is particularly interesting where it depicts a form of society that has now passed away forever:—the almost ideal life that existed in the cultivated families of the South before the war. This is described from the standpoint of a native who was, at the same time, one of the wisest and kindest of men,

able to observe with the trained eye of science, and yet to feel for the lowliest slave. I predict that this autobiography will take high rank among publications of its class.

Much of my information is derived from this source; and I shall endeavor, as far as possible, to let Prof. Le Conte's own words speak for him, since they will paint a picture better than any that I could outline.

Joseph Le Conte was born Feb. 26, 1823, at Woodmanston plantation, Liberty county, Georgia. His father's family were Huguenots, and traced their ancestry back to Guillaume Le Conte, born in Rouen, France, in 1659, who left Rouen in 1686, just after the revocation of the Edict of Nantes, and settled in New Rochelle. One of his descendants, William, took a prominent part in the revolutionary movement in Georgia. He was a member of the "First Council of Safety" in 1775, and was on the so-called "Black List" of "those Rebel Councillors," prepared by Sir James Wright and sent to King George III.

The second son of William, John Eaton Le Conte, was born in 1730. He had three sons: William, who died without issue; Louis, the father of Professor Joseph, the subject of this sketch, and of Professor John Le Conte, the physicist; and John Eaton, the father of John L. Le Conte, the distinguished naturalist.

Louis, the father of Joseph, was born in New York in 1782. He graduated at Columbia College, and then studied medicine, the better to care for the slaves on his father's plantation. He returned, at the age of 28, to Liberty county, which was a Puritan colony, and very orthodox and exclusive. In 1813 he married Anne Quartermain, one of these Puritans, and a refined and lovely woman. They had four sons and three daughters, of whom Joseph was the fifth child and youngest son. Two of these sons died in early manhood, and both of the others became distinguished men.

Joseph's mother died when he was only three years old, and he was brought up by his father with the most tender care. This father was a very remarkable man: a good physician, a skillful chemist and naturalist, a great hunter, fond of all manly sports, and a passionate lover of nature. Young Le Conte owed much to his father's training; but he was partly prepared for college by Alexander Stephens, who entered into all the

sports of his pupils, and strongly impressed them with his own intense hatred of lying and all forms of deceit. His training for college comprised the "Three R's," Latin and Greek through Livy and Xenophon, and mathematics through algebra and geometry.

His life on the plantation at that time was an ideal one; and, as one reads his description of it in his autobiography, one cannot but regret the passing away forever of a stage of civilization that made such an existence possible. It was an admirable training for the future lover of Nature. Hunting, fishing, boating, swimming, riding, were constant sources of enjoyment and profit. In all forms of athletics he was wonderfully proficient. Of a slight but wiry build, he was capable of performing many feats of strength and agility better than many strong men of nearly double his weight. He says of himself:

"Now, at 77 [a year before his death], swimming is still as easy as, and I think a little easier than, walking. Slender, with long limbs and small bones, I have very large lungs, and can inhale over 300 cubic inches of air; hence my body is much lighter than fresh water. I can lie motionless, breathing perfectly naturally, for any length of time; and, in fact, I believe that I could go to sleep in the water."

Swimming was by no means always a safe recreation on the plantation, on account of the alligators. The boys didn't much mind the small ones, say up to six feet or so; but the old ones were considered dangerous, and he mentions with great delight the capture of a big one, 14 feet long, which, with a hooked pole thrust down its throat, took 25 negroes to drag from its hole.

At 14 he was prepared to enter college, but it was wisely decided to have him wait a year; so at 15 he went to college at Athens, Ga., and graduated in 1841. Of this period, he writes:

"I may add, here, that for me the so-called dangers of college-life never existed. I saw much of vicious conduct among students, of course; but whether such example injures or not depends entirely on inheritance and early training. For myself, I never felt the least temptation to join in vicious courses, nor have I ever been enticed by others to do so. College-students are not so bad as some seem to think. They never deliberately try to lead anyone astray. They simply seek congenial association. Indeed, I believe that college is the safest place in the world for young men. It is impossible always to remain in the bomb-proof of home. One must go out into the world and fight the battle of life. Now, college-men are a picked set, far safer than the average."

While in college, he never touched cards or liquors, although later, as a man, he was accustomed to use wine at table.

"Instead of sowing any wild oats and reforming afterwards, I have steadily become more and more liberal in my thoughts and feelings about such things. This is as I believe it ought to be. Vice is mere *weakness*. Evil consists in mere *abuse*. Now, in youth, strength is not yet acquired; rational use is not easy, and therefore had better not be attempted, except under the shelter of the home-roof."

"Refined ladies to me then—and I confess to something of the same feeling yet—were superior beings, belonging to another and higher and purer existence. I simply worshipped them. Association with them produced in me a delicious delirium, an ecstatic joy and exaltation. I have much of the same feeling yet, though modified and purged of its extravagance by experience. In these days it has become the fashion to ridicule this romantic feeling toward woman; but there can be no doubt it is the greatest of all safeguards of the purity of young men."

He delivered a Junior oration in 1840 and the Senior oration in 1841. Of these productions he says:

"To show the double tendency of my mind toward Science and Moral Philosophy, the title of one was 'True Greatness,' which I took to be mainly *moral worth;* of the other, 'Love of Truth the Highest Incentive to Effort.' Both of these I burned many years ago, in disgust of their almost childish crudity and immaturity. I wish now I had preserved them. We grow more tolerant as we grow older. The fact is, my ability to write anything of value came very late. I never was, and am not now, a facile writer. To me a written production of any kind is literally a piece of thought-work. It is not, however, a manufactured article, but a *child* of the brain. It is not *made,* but *born*—born of much labor and with many throes. Of course, therefore, I never write until I have independent thoughts of my own."

I have already referred to the strong religious strain in his ancestry, Huguenot on the one side and Puritan on the other; and I mention another important epoch in his life, in his own words, as it sheds a strong light on the subsequent interest he always took in the religious bearing of the theory of Evolution, and his determined purpose to find a solution for the apparent conflict between science and religion:

"During a religious revival in the churches, when I was in the Junior class, Lewis (a brother) and I joined the church. Our church at Midway, Liberty co., was Puritan Congregationalist. There was no church of that kind at Athens. The nearest to it in faith was the Presbyterian. My friends did not think it well to wait till we returned to Liberty. The Presbyterian was good enough. Thus it was that I became a Presbyterian instead of a Congregationalist. Indeed, the history of our family was peculiar in this regard. My ancestors were, of course, Huguenots by blood and faith. In early colonial times the Huguenot church in New York became at one time so weak, financially, that it was compelled to save itself from extinction by putting itself under the protection of the English Colo-

nial Government, and became Episcopal. It so remained ever in New York. The old Huguenot church in which are recorded the births, deaths and marriages of my ancestors back to the original Guillaume—the Eglise de St. Esprit—is still a French Episcopal church. It has now been moved up to 27th st. On coming to Georgia, where there was no Episcopal church, my father attended regularly the Congregational church at Midway, of which my mother was a member, and of which my elder brother and sister were also members. My father never connected himself with the church, although all his children were baptized there. Circumstances already mentioned connected Lewis and myself with the Presbyterians. It is not strange, then, that, with such a family history, I cared little for denominational differences. Of my own children, one is a Presbyterian, two are Episcopalians, and one is not a member of any church; and he is as good, for all I can see, as any of them.

"This revival and my union with the church was undoubtedly a very great crisis in my life. If there ever was a sudden, almost miraculous conversion, mine was one. I passed through all the stages described in such cases—*i.e.*, a period of great distress, of earnest prayer, of exercise of faith, sudden sense of acceptance, intense ecstatic joy for deliverance, and trust and love of the deliverer. The sense of fatherhood of God and brotherhood of man was vivid and full of delight. Life took on a new and glorious significance. All men became dearer to me, and even Nature assumed a new and more beautiful appearance. Literally, there was a new heaven and a new earth. The sky was never before so blue, the clouds so grandly massy and white, the grass so freshly green, nor the stars so bright. The sense of joy was so great that my breast seemed to swell almost to bursting. But the real permanent change was a sense of deliverance from the bondage and the fear of death and the hereafter which, under the spell of the old orthodoxy, had always, in thoughtful moments, oppressed me. My spirit was set free. I was now the child of God and the brother of Jesus. I had now a really noble object in life—an ideal to be sought—an evil to be fought against. This I have never lost. It has been the most powerful element in the formation of character and in the determination of conduct. However much I may have changed my opinion as to the miraculousness of the process, this change of relation toward the spiritual world has remained as an eternal heritage. Delusion! some will say. No—*it was the old fear that was the delusion.* The change was not the establishment of a new relation, but the establishment of the true relation which already existed."

He was strongly urged, about this time, to become a preacher of the Gospel. He adds:

"At that time I did think very seriously of it; but my scientific tastes prevailed and carried me towards medicine instead, and I have never regretted it. One may be a preacher of righteousness in more ways than one."

He graduated at Athens, Ga., in 1841, at 18 years 5 months. There was then no opportunity to study nature for its own sake, and as the nearest approach to it we find him, in 1843, a student of medicine in the College of Physicians and Surgeons in New York. In the summer of '43–4 he took a trip of several months, with one of his cousins, right into the heart of what was

then a wilderness, inhabited only by Indians and Indian agents. His course took him through the Lake Superior country (at that time just being prospected for copper) into Canada, and then down the Mississippi river, long before such towns as Minneapolis were founded. His journal of this trip reads like the story of Robinson Crusoe, and is full of interest; but I give only the following incident to show the spirit of the boy then, and of the man who always seemed to keep the springs of youth fresh within him:

"What a glorious swim I took in the roaring cataract that afternoon!* Some 29 to 30 Indians, men and boys, had come from Fond-du-lac to visit our camp. As I went down the cataract with railroad speed they watched me with the greatest interest, cheering when I passed, and screaming with delight when I came out victorious. I bantered them to join me, but neither entreaty nor jeering would induce them to try. I went down repeatedly (walking up by land each time), leaping and playing in the roaring torrent, laughing and screaming with delight."

This trip left a great impression upon his mind. He made *en route* a number of geological observations (the importance of which he was then too young to realize), which were afterwards confirmed, and more fully appreciated, by other observers.

In 1845 he graduated from the medical school, and settled down as a practicing physician in Georgia.

On January 14, 1847, he was married to Caroline Elizabeth Nisbet, the daughter of Alfred M. Nisbet, Esq., at Midway, near Milledgeville, Ga. This marriage proved a very congenial one, and has occasioned the following eloquent lines, which, written at 77, a year before his death, and after half a century of wedded life, show the warmth of his nature, the soundness of his judgment, and the happiness of his experience:

"I have referred to love and marriage as the second great crisis in my life. There may be love with marriage, and, alas! marriage without love. These two, love and marriage, are necessary supplements of each other, and must be combined to afford the highest spiritual growth. Love, *romantic love*, inflames the imagination and æsthetic sense, kindles the sense of beauty in the human person, in art and literature. But this is not enough. Marriage is necessary to bring about another kind of love—of the heart and the affections—*unselfish, self-effacing love.* The first grows up quickly, but as quickly sheds its flower-like beauty after marriage, unless supplemented by wedded love, which continues and grows to the end of life, not destroying, but only chastening, the extravagancies of the former. The one may be likened to the Greek spirit, with its intense love of beauty, intense

* At the Dalles of the St. Louis river.

enjoyment of life, physical and temporal, but adding to it the apotheosis of woman, which it derives from the Teuton. The other may be compared to the Christian spirit of self-sacrifice, but adds also the apotheosis of woman as virgin-worship. The one must not displace, but supplement the other. The two, the Greek and the Christian, must be united. They are united in every true marriage. They are becoming so in every enlightened modern society."

In the practice of medicine he was moderately successful; but his heart was not in the work. He felt, probably, more keenly than most, the responsibility for the life of his patients, and the lack of preparation which the medical training of that time gave for what he himself terms "the awful responsibilities of a medical practitioner." Then, too, it was characteristic of the man to shrink from practical details; they did not interest him; his nature reached out to solve the larger problems of the mind. He had at this time three medical students, and teaching them interested him far more than the practice of medicine. He confesses to having felt a strong sense of wasted life, though he carefully concealed it from all, even from his wife.

Richard Owen, the comparative anatomist, first interested him in the "homologues of the human skeleton;" and this led him to decide, shortly after (in 1850), to become a pupil of Agassiz. He went to Cambridge in August:

"The University does not open till October. But that does not matter. I did not come to Harvard to enter the University, but only to study with Agassiz, and we (Dr. Jones and myself) went right to work. The first work he put us at was very characteristic of the man. He thought a moment, and then pulled out a drawer containing 500 to 1000 separated valves of *Unios*.

"There were 50 to 100 different species, all mixed up. 'Pair these valves,' said he, 'and classify into species—names no matter—but separate in species.' He left us alone—very severely alone. We worked on these shells for one whole week. He looked at the work from time to time, but made no remark. Finally, we told him we had done the best we could. He examined carefully, and was greatly pleased. It happened just then that there entered the room a friend of his, just from Europe, M. Ampère, son of the great electrician. He introduced us, and remarked that these pupils of his had just amended correctly the classification of Lea, the great authority on *Unios.*

"I only give this as an example of his method of teaching. He constantly carried it out, with some modifications. He set us tasks; we worked unaided, with only a hint here and there. As we became better acquainted, however, finding us already well-advanced in thoughtfulness, he often gave us long talks, expounding his biological philosophy, and inviting discussion, which we were not slow to accept. He thus scattered unpublished thoughts and suggestions broadcast on all sides with a free hand."

"There are two types of great men. Men of one class are great by the quantity and importance of their work; but when you come in contact with and measure

them intellectually, they seem of ordinary stature. Their work is greater than themselves, though surely patience and persistence are admirable qualities which ought to be added to their work in estimating their greatness. Those of the other class, the nearer you approach them the greater they grow. They are themselves greater than all their visible results. These are the great teachers. Their spirit and enthusiasm are contagious, their personality is magnetic. They not only think intensely, but they are the cause of thought in others. Agassiz was pre-eminently of this class."

Later, he joined Agassiz in his famous trip to study the coral-reefs of Florida, and he gives the following very interesting reminiscence, showing the nervous pressure under which this great teacher worked:

"The collections were enormous, for the whole population, especially the sailors, 300 to 400 in number, collected for Agassiz. The keen delight, the almost childlike glee of Agassiz, when anything new was brought him, pleased these children of nature immensely. 'One touch of nature makes us all akin.'"

"I never saw any one work like Agassiz—for fourteen hours a day working under high pressure, and smoking furiously all the time. The harder he worked, the faster he consumed cigars."

It is, perhaps, not surprising that Agassiz had a nervous breakdown soon after. He was probably, even then, showing its first symptoms.

A year later (in 1852) Le Conte accepted the Professorship of Science at Oglethorpe University, Midway, Ga. He was expected to teach all the sciences except astronomy, which went with the chair of mathematics. For $1000 a year he actually did teach mechanics, physics, chemistry, geology and botany. A year later, he was called to a better position in his own university at Athens, Ga., where for five years he was able to confine himself to natural history, though he had to teach French for a year. In 1857 he was called to the Professorship of Chemistry and Geology at South Carolina College, Columbia, S. C., where he remained till after the war.

Speaking of the outbreak of the war of '61, he says:

"At first I was extremely reluctant, and even opposed to the movement. I doubted the necessity of secession; I dreaded the impending conflict and the result. A large number of the best and most thoughtful men in the South felt as I did. But gradually a change came about—how, who can say? It was in the atmosphere. We breathed it in the air; it reverberated from heart to heart; it was like a spiritual contagion—good or bad, who could say? But the final result was enthusiastic unanimity of sentiment throughout the South. Those who were the latest and the most reluctant, because they saw the seriousness of the result, were

also the most earnest and most reliable. Those who did not join in the movement (with very few exceptions, like Pettigrew) were untrue men in every way, both North and South alike. Copperheads and scalawags, with some exceptions, were alike untrue. I spoke of Pettigrew as an exception. Pettigrew from the first, and throughout the war, was always a Union man. He spoke openly, never concealing his opposition to secession. He said the State was demented, but submitted quietly and sorrowfully. Every one accepted his views and had the greatest confidence in his integrity. He loved the State, but believed she was rushing on ruin. After the war, the confidence of the State was shown by giving him the codification of the laws."

Prof. Le Conte carried on his teaching till the college was disbanded, as the war became more desperate, and then offered his services to the Confederates, and was employed as chemist and geological expert in the search for deposits of niter and the manufacture of explosives. He suffered all the horrors of war except death in his immediate family. For three years he had the barest and coarsest of food, never tasting tea, coffee, or sugar for that time, and, strange to say, though fond of them, hardly feeling their loss. At the end of the war, like many others, he was in rags, and was compelled to wear the uniforms of Federal soldiers who had died in the hospitals; for cloth, and even its raw materials, had practically ceased to exist in parts of the South. All his property was gone. His Georgia home had been in the path of Sherman's army, and everything he possessed except the land was gone. At one stroke of the pen, the Emancipation proclamation had taken from him something like $75,000 worth of slaves. But at this last loss he was not disposed to grieve. He had inherited his slaves, and for a long time his family had neither bought nor sold any. They had regarded their slaves as wards for whom they were responsible, rather than as mere chattels. His father had actually studied medicine the better to look after their welfare, and the son had felt that he ought to do the same thing. This he could only do by sacrificing his ambition for a scientific life —a sacrifice to which he had not brought himself; but still the care of those slaves had always been a weight upon his conscience. Hence, though in financial distress, he was really relieved when this weight was gone.

Regarding the actual loss to the South from the emancipation of the slaves, Prof. Le Conte maintained at the time, and always afterwards, that it was not necessarily a loss like that due to the burning of a house. He pointed out that

"Where the black labor remains reliable, and the management is judicious, the land makes as much as ever it did, and the owner is as rich as ever he was; he has suffered no loss. . . . . But in some places the labor continues to be utterly unreliable. This is especially true of the so-called 'black belt,' where the blacks are greatly in excess, and still more especially true in Liberty county, Ga., where my own landed property is situated. I have there more than 2000 acres of land, half of it rich land. It has never made me one cent since the war. The negroes will not work for wages. They can live on fish, crawfish and oysters, almost without work. A little patch of cotton will make more tobacco and coarse clothing than they can use. They have no ambition to improve, and live almost like animals. The whites have nearly all quit the country and gone somewhere else. The whole lower and richer part of the county is practically given over to the blacks."

In this connection, in view of the still unsettled state of the race-question in the South and the very large addition to our race-problem that has come to us as a result of the Spanish war, it is worth while to mention a paper by Prof. Le Conte, entitled "The Race Problem in the South," which was read before the Brooklyn Ethical Association and published in a volume issued by that society, entitled "Evolution: Man and the State." (New York: Appleton & Co., 1892, pp. 349–383.) This paper was written from a personal knowledge of the question, and brought to bear on the problem the laws of evolution, as applied to the study of race-contact and survival. He first shows that the problem is not soluble by race-blending, for the simple reason that the blend is sterile. He then goes on to show that when two races that cannot blend are brought into intimate contact, so that they cannot escape from each other, there are two possible solutions—the extinction of one, or the management of the governmental policy by the superior race. He illustrates this by the example of a thousand adults and a thousand children of their own race upon a desert island. No one would think that the children should govern. Their very safety depends on government by their wiser seniors. Suppose, now, instead of the one thousand children, there should be substituted one thousand adult savages; peace could only come by the extinction of one or the other of these races, or the submission of the inferior to the government of the superior race in the common interest. He contends that education and a moderate property-qualification should be made the indispensable requirements for suffrage. And he observes that, for the lower classes, the latter is perhaps the more important of the

two, as it indicates the presence or absence of certain moral qualities, such as industry, thrift and self-control, indispensable qualifications for citizenship. He remarks, elsewhere, that, shortly after the war, when an income-tax was enforced in South Carolina and his only income was his salary of $2000 per year, he was taxed 5 per cent., or $100; and *that this tax of $100 was more than was paid at that time by the entire Legislature (mostly composed of negroes), who made the laws for the State!* Among other acts, this Legislature passed a law admitting all negroes to the University without any qualifications!

This is not the place for any discussion, or even for an expression of personal approval, of the views of Prof. Le Conte on such a subject. They have been given in the foregoing condensed statement as a necessary part of any complete picture of the man. But it is not improper to call attention to them as a contribution to pending discussions from an exceptionally sincere, keen, wise and kindly observer.

In 1869 Prof. Le Conte left Columbia to accept a call to the University of California, whither his brother John had preceded him a year before. He was expected, at first, to teach, alone and without assistants or laboratory appliances, botany, zoology and geology. He was compelled to give his instruction entirely by lectures. This he did for many years; and he developed a method of lecture-instruction that has probably never been excelled by any teacher of these subjects. Later, he was relieved from the heavy task of carrying these three subjects, and confined his teaching entirely to geology. But it was doubtless fortunate for his students that he taught these related subjects for so many years; since otherwise his wonderful grasp of the doctrine of organic evolution would have been impossible. As it was, he welded these three subjects, zoology, botany and geology, all studied by the comparative method, into an organic unity that made a never-to-be-effaced impression on all his hearers.

It was probably for him, and certainly for California, fortunate that he came when he did to the State University. One can best understand this from his own words:

"I have said that my intellectual activity was powerfully stimulated by my coming to California. There were many reasons for this: First, the reaction from the long agony of the war. Abstract thought was almost impossible, for

anxiety during the war, and the presence of its ruinous results afterward. Second, the splendid field for geological research offered here. Third, contrary to my expectations, I found here an exceptionally active, energetic, and intelligent population. What California wanted then (and still to some extent wants) is a more thorough organization of society—an organized public opinion—conventions, traditions—with them, wholesome restraining influences on the weak and the vicious. But the strong and the virtuous do not need these—indeed, are perhaps better without them. Family and name have little influence here; every man must stand on his own merits.

"I threw myself into my work with all my energy. I enjoyed my teaching intensely, and this made my teaching correspondingly interesting to my students. I never tire of my subject. Although I have gone over my course in geology now fifty times, I am still as interested in it as ever. Although the whole subject is perfectly familiar to me, I never enter my lecture-room without two hours' intense preparation. I must revive my interest, I must get up steam. I am firmly convinced that investigation ought never to be separated from teaching, as many suppose,—that not only is one a better teacher from being an investigator, but he is also a better investigator for being a teacher. Nothing so clears up the thought as the earnest attempt to make it clear to others by personal address. Almost every good thought I ever had came first into my mind during the heat of direct preparation for my class-lectures. Nearly everything I ever wrote was first given in my class-room, and written out and perfected afterward. Whatever success I have ever achieved in teaching has been the result of my intense interest in my subject and in my students."

As one of these students, I can well testify to the truth of the above lines. Daily, for years, have I seen his agile figure eagerly stepping off for a brisk morning stroll of half an hour. To the last he kept his physical vigor and activity through attention to the laws of health. At nine, with his blood in active circulation and his lungs full of the freshness of the morning, he shut himself up alone in his study and paced slowly up and down, reviewing those beloved notes of his—long, narrow sheets of pale brown paper, inscribed with a logical framework of ideas to build on.* Then, at eleven, he appeared before his class, full of the inspiration of his great theme. It was no wonder that he carried all his hearers with him. His afternoons were given to writing, and his evenings he reserved, as far as he could, for general reading. It is to the honor of the Regents of the University that, despite many

* Certain peculiarities of his style as an author are probably largely due to his habit of constructing these lecture-notes as a framework for his discourses. For instance, his liberal use of capitals and italics. This probably came about, to some extent, at least, through the necessity of emphasizing certain words and phrases in order to catch the eye, and the very natural extension of this habit into his written productions.

financial stringencies, they relieved his energies from the drudgery with which so many college professors are loaded, and enabled him to live out his long life and use his great abilities to the best advantage.

I well remember the first time I heard him lecture: it was in the basement-hall of one of the local churches. As I wandered down the steps, my ear was touched by a thin, rather high-pitched voice, vibrating like a high-strung but clear and true violin string. It was a voice of wonderful flexibility, and it followed with perfect naturalness every phase of his theme. The peculiarity of the voice impressed me even before I had seen the speaker. But I stopped to listen; and I forgot the voice in the theme.

Many times (and with new pleasure every time) have I heard him repeat an address often delivered before; and I have noticed that he used almost the same words on each occasion, though his notes were never written out in full, and there was no attempt at memorizing. His subject was so thoroughly thought out, so entirely his own, that the best words naturally suggested themselves to his mind at the right moment. There was no striving after effect; all was the result of intense interest and thorough mastery of his subject.

Never a controversialist, he was forced to write one of his best books simply to correct the errors of others. These were no less men than Wiedemann, Helmholtz and Clapeyron, Tyndall and Raoul Pictet. He had peculiar power in controlling the muscles of the eyes, and singular acumen in analyzing their observations. When still a young man, he saw a stereoscope for the first time, and listened to his older scientific friends, exclaiming, as they viewed it, on the remarkably beautiful demonstration which it furnished of the correctness of the then accepted Wiedemann theory of binocular vision. When his turn came to examine the instrument, he noticed that, if he focused his eyes on the near lines in the figure, the far ones disappeared, and *vice versa*, and perceived that this was in direct opposition to the Wiedemann theory. His remark, "Yes, it is beautiful; but it disproves the Wiedemann theory," was received with incredulity; but he lived to see his views accepted. Though not at first greatly interested in the subject, his peculiar powers of vision enabled him to detect, one after another, the

faulty interpretations of the many distinguished physicists who attempted the problem, until his many papers grew at last into his volume on "Sight," now the accepted authority on that subject, which exhibits his capacity of careful analysis and resources of a high order in the conduct of experimental investigation with simple means.

No one can have followed even this brief outline of his life without feeling the breadth of his training and the wide outlook of his sympathies. But our Institute looks upon him chiefly as a leader in geological science.

His first geological studies date back to that long trip to the Lake Superior region, where he was present at the first opening-up of the copper-mines; but even then he was more interested on the scientific than on the technical side. His work with Agassiz on the coral reefs of Florida gave another impetus to his tastes. His search for niter-deposits for the Confederate Government, during the dark days of the war, brought him into the practical branch of our profession. But his coming to California, then a virgin field to geologists, inaugurated a new era in his life.

In his vacations he ranged the foot-hills and the Sierras of California, the Cascades of Oregon, and then into British Columbia. He visited the Comstock mines of Nevada in their prime. He first noted the extent and significance of the great Columbia lava-flood that stretches down into northern California. He developed and perfected his theory of mountain-formation, and worked out a number of important problems in California geology. Perhaps our greatest interest attaches to his studies in the origin of metalliferous veins. His visits to Virginia City, Nev., to the California gold-veins and auriferous gravel-deposits, and, most of all, to the Sulphur Banks, Cal., and Steamboat Springs, Nev., where traces of cinnabar (and, in in the latter, also gold, silver, and copper) were still being deposited, stimulated his interest to the highest pitch. I well remember that, two years before this time, I was particularly interested in studying the cinnabar-deposit at New Almaden, and had come to the conclusion that it could not have been formed by the sublimation of the cinnabar, as was then commonly supposed, but must have been deposited from solution. I shall never forget his delight when I brought him a beautiful, solid mass of crystals of artificial cinnabar that I had produced in

the laboratory by the action of a superheated solution of alkaline sulphide on the black amorphous sulphide of mercury. He was more rejoiced that one of his students had made this discovery than if he had made it himself. When, later, he was able to catch nature in the act, as it were, at Steamboat Springs and Sulphur Banks, his satisfaction was complete. His interest in this subject never waned.

The world is certainly indebted to him for his "Elements of Geology," which presents the subject, stripped of every needless technicality, so as to make it interesting to every intelligent reader. I do not know a book in any language which so clearly opens to the beginner the delights of the science he loved best; and anyone who has imbibed its spirit has drawn a lesson from the book of nature which will always give to life new meaning and interest.

He was much interested in the remarkable fossil footprints that had been discovered in some sandstone-beds. Dr. Harkness and others had claimed that some of these had been made by prehistoric men. Prof. Le Conte examined them with Dr. Harkness and several others, and each wrote a paper, Dr. Harkness arguing in favor of the human origin, and Dr. Le Conte against it. It is needless to add that the latter view is now accepted. The following interesting observations were made at this time by Prof. Le Conte concerning the convicts who were employed in blasting out fresh exposures in the formation:

> "While here, my observations on criminals interested me greatly. They enjoyed the work and the investigation immensely and very intelligently. We were all working together, and all intensely interested together. We entirely forgot that they were criminals, and some of them murderers. We were all simply fellow-men, and for the time companions. For all we could see, they were much like average men, neither better nor worse. The effect of the work-sentiment on them was wonderful. Before sullen and dull, now bright, eager, cheerful and happy. What a reformatory measure such work would be, if it could be continued indefinitely!"

But it is probably as a teacher of the new gospel of Evolution that Prof. Le Conte will be best remembered. He was not one of the first to accept it. As a disciple of Agassiz, who never accepted it, he at first was strongly opposed to it; but the more he studied it, the more he attempted to explain it to his

students, the more its importance was forced upon him. His strong religious nature made him weigh it in the balance, lest it might contain some flaw, or unhappily undermine the religious faith of some tender youth. I myself remember his early reservations in dealing with the subject; but year by year these became fewer and fewer, until at last, when all became clear to him, he became the truly inspired teacher, the voice of John the Baptist in the wilderness, crying out, "Prepare ye the way of the Lord, make His paths straight." No religious service could have more of reverence in it, or a deeper sense of contact with the infinite possibilities of life and death, than those lectures of his on Evolution.

The way his famous book on "Evolution" came to be printed is also interesting. Henry Ward Beecher had just become a convert to the new view, and, with characteristic courage and promptness, one of its most ardent advocates. Somewhere about '85 he came to California on a lecture-tour. Mr. Sherman Day, of Berkeley, a neighbor of Prof. Le Conte, asked him for copies of some of his papers on Evolution, to give to Mr. Beecher. After reading them, Mr. Beecher wrote to Prof. Le Conte (personally unknown to him at that time), urging him to write a book on the subject, saying, indeed, that he owed it to the world to do so. Prof. Le Conte had often thought of doing so, but shrank from the task—rather from the abundance of material than the lack of it. But this appeal decided him; and a couple of years later the book was finished. He says of it:

> "Its success exceeded my utmost expectation. The intelligent public seemed to have been waiting for such a book, especially the third part, *viz.*, 'The Relation of Evolution to Religious Thought.' Since its publication I have received letters from clergymen personally unknown to me, and of every denomination, thanking me for the boldness and yet the temperateness of the book. I have also received letters—thirty or forty—from young men personally unknown to me,—young men of high intelligence, many of them scientific,—from all parts of the United States, thanking me for a book which had saved them from rank materialism. I have also received letters from England, France and Italy, from men of the highest distinction. There can be no doubt that the book was timely and has done much good."

I remember meeting, at the home of a distinguished orthodox clergyman in Berkshire county, Mass., shortly after the book was published, the president of one of the most orthodox

colleges in America, himself an eminent clergyman. When he learned that I was from the University of California, he at once spoke with the greatest admiration of this book. I asked him if he accepted its conclusions, and was much surprised to hear him say, most emphatically, that he did; and then he added: "*I regard the book of Genesis simply as a charcoal-sketch, and we must look to Science to fill in the outlines of the picture!*" Truly the point of view has changed for the better in the last decade; and no one has contributed more to bring about this result than Joseph Le Conte.

It would be out of place for me to make a critical estimate of his work, even if I felt equal to the task; but I give, instead, his own modest estimate of it, as furnished in his autobiography—which is certainly an underestimate.

"Now, looking back over a long life of incessant activity, what have I done of value to the world? What have I added to human thought? What influence for good may I hope to leave behind?

"I. *In Science.* To touch only on the most important points:

(a) My paper in '59, 'On Correlation of Vital and Physical Forces,' I think, gave both impulse and greater definiteness to scientific thought on that subject. Carpenter, in the last edition of his Physiology, gives me credit for distinct advance on this subject.

"(b) My researches on the phenomenon of Binocular Vision, I am sure, did clear up the thought in this field. I claim, and have been generally accorded, the credit of several original thoughts which have remained the permanent possessions of science: (1) Demonstration of the real nature of the Horopter. (2) Demonstration of the true theory of binocular perspective. (3) Demonstration of certain fundamental psychical phenomena in binocular vision, and a new mode of diagrammatic representation based thereon. These phenomena had been observed by some, but not understood. Their explanation had been hinted at by others, but never clearly brought out before. (4) Certain peculiarities of phantom-planes not explained before.

"(c) In geology, I believe some real substantial advance in science was made in my series of papers: (1) On the Structure and Origin of Mountain Ranges. (2) On the Genesis of Metalliferous Veins. (3) Especially those on the Critical Periods in the History of the Earth. (4) The demonstration of the Ozarkian, or, better, the Sierran, epoch as one of great importance in the history of the earth. I might mention several others that I believe are of prime importance; but I am willing to stand by these.

"(d) In Biology, my views on Glycogeny, although not yet certain, have undoubtedly contributed to clearness of scientific thought on that important subject.

"II. *In Philosophy.* I look back with especial pleasure on my writings on Evolution. I lay no claim to the discovery of new facts bearing on the theory of evolution, but only to have cleared up the nature and scope of evolution, and especially to have shown its true relation to religious thought. It is well to stop a moment, to show the different rôles of different thinkers on the advance of this

subject. Leaving out of account mere vague philosophic speculations like those of ancient philosophers, and those of Swedenborg in modern times, I would say that the rôle of Lamarck was to introduce evolution as a scientific theory. The rôle of Darwin was to present the theory in such wise as to make it acceptable to, and accepted by, the scientific mind. The rôle of Huxley was to fight the battles of evolution, and to win its acceptance by the intelligent popular mind. It was the rôle of Spencer to generalize it into a universal law of nature, thereby making it a philosophy, as well as a scientific theory. Finally, it was left to American thinkers to show that a materialistic implication is wholly unwarranted—that it is entirely consistent with a rational theism, and with other fundamental religious beliefs. My own work has been chiefly in this direction. In my lectures in 1872 on 'Religion and Science,' I might be called a reluctant evolutionist; yet, even then, in the 16th chapter of my book, I try to show the mode of origin of the spirit of man from the *psyche* of animals by a process of evolution. In a few years, however, I was an evolutionist thorough and enthusiastic—enthusiastic not only because it is true, and all truth is the image of God in the human reason, but also because, of all laws of nature, it is by far the most religious, *i.e.*, most in accord with religious philosophic thought. Indeed, it is glad tidings of great joy which shall be to all peoples. Woe is me if I preach not that gospel! Literally, it can be shown that all the apparent irreligious and materialistic implications of science are reversed by this last child of Science—or rather this daughter of the marriage of Science and Philosophy. During all my life I have striven earnestly to show this. My book on 'Evolution and its Relations to Religious Thought' is the embodiment and result of these strivings, although I believe that, if I wrote it again, I could add much to the argument. I commenced this line of thought in 1871, I believe, and therefore claim that I was the pioneer in this reaction against the materialistic and irreligious implication of the doctrine of evolution. I can look back on this with greater pleasure than on anything else I have done. At first I suffered some (not much) obloquy on the part of the extreme orthodox people; but I have lived to see this pass away, and all intelligent clergymen coming to my position.

"All, or nearly all, my philosophic writings are more or less connected with the doctrine of evolution; and I regard these as among the most important of my writings. Indeed, my good friend Prof. Howison thinks that the best and most permanent that I have done is in the domain of philosophy, not in that of science proper. But then he is a philosopher; perhaps my scientific friends think differently."

If one were asked to characterize his activities in a single sentence, it could be best done in his own words:

"The domains of Science and Philosophy are not separated by hard and fast lines; they largely overlap. It is in this border-land that I love to dwell."

Perhaps one of the most interesting of Prof. Le Conte's addresses was the one he delivered before the Philosophical Union of the University of California, at its public annual meeting in 1895. The address of the evening had been on the theme, "The Conception of God," a book written by Prof. Josiah Royce, of Harvard University, who had been, as an

undergraduate in the University of California, a pupil of Prof. Le Conte. This book had been the subject of study for some time by the Union. On this occasion Dr. Royce had delivered an address on the subject, and there had been comments and discussion by Prof. Mezes, of the University of Texas (also a former pupil of Le Conte), and our own honored Professor of Philosophy, George H. Howison. The discussion, listened to by an audience of over a thousand, had been an intellectual contest of the most brilliant kind. In striking contrast to the methods of the philosophers were the remarks of Prof. Le Conte, which, however, held his audience from the first to the last, and produced a profound impression.

I had met him that afternoon on the college steps, and had thought, regretfully, that he was beginning to look a little worn. But that night, as his slender, graceful figure appeared upon the stage in evening dress, with his great head of snowy hair shining like a halo about him, he seemed as one inspired. I wish I could give his whole argument; but I must content myself with his introduction and his conclusion. He began:

"I can only admire, not criticize, the subtle method of Prof. Royce in reaching the conclusion of the personal existence of God. I have my own way of reaching the same conclusion; but, in comparison, it is a rough and ready way. His is from the point of view of the philosopher; mine from that of the scientist. I am not saying that his is not the best and the most satisfactory, but only that it is a different way. He has given you his; I now give you, very briefly, mine—as I have been accustomed to give it.

"Suppose, then, I could remove the brain-cap of one of you, and expose the brain in active work—as it doubtless is at this moment. Suppose, further, that my senses were absolutely perfect, so that I could see everything that was going on there. What would I see? Only decompositions and recompositions, molecular agitations and vibrations; in a word, *physical* phenomena, and nothing else. There is absolutely nothing else to see. But *you*, the subject of this experiment, what do *you* perceive? You see nothing of this; you perceive an entirely different set of phenomena, namely, consciousness,—thought, emotion, will, *psychical* phenomena; in a word, a self, a *person*. From the *outside* we see only a physical form, from the *inside* only psychical phenomena.

"Now, take external nature—the Cosmos—instead of the brain. The observer from the outside sees, and can see, only physical phenomena; there is absolutely nothing else there to see. But must there not be in this case also, *on the other side*, psychical phenomena—consciousness, thought, emotion, will—in a word, a Self, a Person? There is only one place in the whole world where we can get behind physical phenomena—behind the veil of matter, namely, in our own brain, and we find there a self, a person. Is it not reasonable to think that if we could get behind the veil of Nature we should find the same, that is, a Person? But, if so, we must conclude an Infinite Person, and therefore the only complete person-

ality that exists. Perfect personality is not only self-conscious, but *self-existent*. *Our* personalities are self-conscious, indeed, but not self-existent. They are only imperfect images and, as it were, separated fragments of the Infinite Personality, God."

He went on to agree with the explanation given by Prof. Royce as to the necessity for moral evil in the world—that it would be impossible for a moral being to exist without freedom to choose between right or wrong,—and continued:

"As already said, then, I believe Professor Royce gives a true answer so far as moral evil is concerned, although he misses the emphasis which evolution gives that view. But other evil—physical evil—he gives up, in his book, in despair. And yet, from the point of view of evolution, this is exactly the form of evil that is most explicable. For as moral evil is a necessity for a progressive *moral* being, just so, and far more obviously, is physical evil a necessity for a progressive *rational* being. As one form of evil is closely connected with our *moral* nature, so is the other indissolubly connected with our *intellectual* nature. Let me explain: The necessary condition of *any* evolution is a struggle with an apparently inimical environment. For example:—the end and goal, the significance, the only *raison d'être*, of organic evolution in general, is the achievement of a rational being—man. The necessary condition of that achievement was the struggle with what seemed at every stage an inimical—*i.e.*, evil—environment. But looking back over the course in the light of its glorious result—the achievement of man—we at once see that what seemed evil is really good. Now, it is equally the same with *human* evolution in relation to physical evil. The goal and end, the *raison d'être*, of social progress is the achievement of the *ideal* man—both in knowledge and character. But the attainment of perfect knowledge is impossible, except in the presence of what seems at every stage an evil environment, and by conflict with it. But evidently such an environment is evil only through ignorance of the laws of Nature. Evil is therefore the necessary spur that goads us on to increase of knowledge. We are but foolish little children at school. Nature, our schoolmistress, chastises us relentlessly until we get our lessons. It is quite evident that, without this scourge of Evil, humanity would never have emerged out of animality, or, having emerged, would never have emerged beyond the lowest stages. It is also evident that perfect knowledge of the laws of Nature would remove every physical evil. Looking back over the course, then, from the elevated plane of perfect knowledge, and perceiving that the attainment of that plane was conditioned on the existence of evil—on punishment for ignorance—shall we any longer call it evil? Is it not good in disguise?

"But it may be answered, 'Yes, this is all true, if we accept evolution by struggle as a necessary process; but why may not that same result have been attained in some less expensive and distressing way?' I answer, Because, as already seen, no other process is conceivable that would result in a moral being; and the achievement of such a being is the purpose of all evolution. One law, one process, one meaning and purpose, runs through all evolution, and that purpose is only revealed at the and. As, in biology, the laws of *form and structure* are best studied in the lowest organisms, where these are simplest, but those of *function* are studied best in the highest organisms, because only there clearly expressed, just so the laws of *process* in evolution are best understood in its lower and simpler stages; but the *end*, the *purpose and meaning* of the whole process from the begin-

ning, is not fully declared *until* the end. That end is the achievement of a moral being; a moral being without struggle with evil is impossible because a contradiction in terms; and the same law must run throughout.

* * * * * * *

"Finally, the true conception of God, as it appears to me, and especially in His relation to us, is closely bound up with the absorbing question of immortality. And on this, I surmise that Prof. Royce and I differ; though I am less sure that we do, judging by his hints of what is coming in his more esoteric lectures next week. But in his book he gives up the question of immortality as insoluble by philosophy. Well, perhaps it is; but upon this question, as upon that of evil, I think a great light is thrown by the evolutional view of the origin of man. . . .

"I assume, then, the immanence of Deity in Nature. Furthermore, as you already know, I regard *physical* and *chemical* forces, or the forces of dead Nature, as a portion of the Omnipresent Divine Energy in a *diffused, unindividuated state*, and therefore *not self-active*, but having its phenomena determined directly by the Divine Energy. Individuation of energy, or self-activity, begins, as I suppose, with Life, and proceeds, *pari passu*, with the organization of matter, to complete itself as a Moral Person in man. . . . God may be conceived as self-sundering His Energy, and setting over against Himself a part as Nature. A part of this part, by a process of evolution, individuates itself more and more, and finally completes its individualization and self-activity in the soul of man. On this view, spirit, which is a spark of Divine Energy, is a potentiality in dead Nature, a germ in plants, a quickened embryo in animals, and comes to birth into a higher world of spirit-life in man. Self-consciousness, from which flows all that is distinctive in man, is the sign of birth into the spiritual world. Thus, an effluence from the Divine Person flows downward into Nature, to rise again by recognition of, and communion with, its own Source.

"Now, observe, and this is the main point: The sole purpose of this self-sundering of the Divine Energy is thereby to have something to contemplate. And the sole purpose of this progressive individuation of the Divine Energy by evolution is finally to have in man something not only to contemplate, but also to love and to be loved by, and, in the ideal man, to love and to be loved by supremely. Thus, God is not only necessary to us, *but we also to Him.* This part of God, self-separated and, as it were, set over against Himself, and including every visible manifestation or revelation of Himself, may well be called a Second Person of the Godhead, which by eternal generation develops into sons of men, and finally into fullness of Godhead in the ideal man—the Divine Man—as his well-beloved Son. By this view there is a new significance to nature. Nature is the womb *in* which, and evolution the process *by* which, are generated sons of God. Now—do you not see?—*without immortality, this whole purpose is balked—the whole process of cosmic evolution is futile.* Shall God be so long at so great pains to achieve a *spirit*, capable of communing with Him, and then allow it to lapse again into nothingness?"

The effect produced by this remarkable address was very powerful. It could not be said to be a demonstration in the strictly logical sense, but those who heard him felt that he had reached out into the outer twilight, beyond the daylight of

reason, and had grasped something more than a shadow. His characteristic power to produce this effect, in handling a difficult subject, was, no doubt, due to his genius for reasoning by analogy. This is commonly admitted to be one of the most dangerous methods of reasoning. But this has always seemed to me to be only another way of saying that only a man of genius is able to discover the true analogy among the thousand seeming analogies that trap the ordinary mortal. Many of the greatest of scientific discoveries have been made by discovering true analogies, even when it was afterwards necessary to corroborate them by the logic of mathematics. It was in this method of reasoning by analogy that Prof. Le Conte was strongest. His long habit of comparative study in zoology, botany and geology had educated to the highest state of efficiency a faculty naturally very strong in him. And the skill with which he used it aroused the admiration of all who heard him. It enabled him to bring out the common ideas in apparently conflicting theories, and to show that these conflicting views were often only partial views of the same truth which could be wholly grasped only by combining them. No one could be associated with him in the class-room without being ever afterwards conscious of a wider and a more generous outlook.

It would be an omission not to mention one of the marked characteristics of genius that Joseph Le Conte possessed in a remarkable degree; that is, openness and flexibility of mind. These qualities he retained to the very last. At seventy-eight his mind was as open to new impressions as that of a little child. His mind never seemed to ossify and harden, as minds often do with age. His greatest work has been in spreading the gospel of evolution. But he was nearly forty-eight before he became a convert to the theory; and yet he put all the enthusiasm of youth into its study, and, when he became convinced of its truth, he showed the same eagerness in its defense. Some of his best work was his last.

While partly natural to him, there is no doubt that a great deal of this flexibility of mind was due to a flexibility of body; for he preserved his powers of body and mind to a much greater age than his brother John. This difference he himself attributes to his early and continued love for athletic exercises

and manly sports, which was much more marked than in his brother.

It was natural that such a man should be a lover of art in all its branches: poetry, the novel, the drama, sculpture, painting, architecture and music. Indeed, he was quite a skilled performer upon the flute, and took the greatest pleasure in all forms of musical composition.

His was a singularly fortunate life. Except for the brief nightmare of the Civil War, it all flowed like one of our Sierra streams, bright and clear from the mountain-tops down through the green pastures.

In many respects his life and character remind one of Mendelssohn. We find the same charm of manner; the same playful fancy and genial, kindly humor; the same high purpose and pure, noble nature; the same harmonious relation to life, and the same sunny cheerfulness of disposition. They were alike fortunate in early home-influences, and were both saved from that rough contact with the world and the too often brutal struggle for existence which crushes the weak, and hardens and deadens the sympathies of the strong. Each was the center of a circle of admirers and devoted disciples. But Mendelssohn was cut off in the flower of his youth, while Le Conte was allowed to live out his useful life to the end.

Mendelssohn found his greatest pleasure in those harmonies which, through the ear, stir the deeps of the human soul. Le Conte loved to study the seeming discords of nature, and to follow the resolution of those jangling chords into the richer harmonies with which the Great Composer gives interest and meaning to the Cosmic Symphony.

It is, perhaps, his greatest triumph that he enabled many thousands of young men to look on life with a new interest, to endure its necessary evils as part of a greater good, and to be content each to play his part, however subordinate, in the firm conviction that it was essential in the Great Symphony. It was as teacher that Joseph Le Conte was greatest; and this was his greatest lesson. When all else that he taught has been forgotten, this conviction will remain in the minds of his hearers, "like the shadow of a tall rock in a thirsty land."

In California his name will always be associated with the Sierras that he loved, and the Yosemite valley, in which he

breathed out his gentle spirit, will henceforth be hallowed ground.

Writings of Professor Joseph Le Conte.

1850. Science of Medicine, *So. Med. and Surg. Jour.*
1853. Salt Lakes, *Ga. Univ. Mag.*, Apr.
1854. Sun Drawing Water, *Ga. Univ. Mag.*, Sept.
1855. Utilitarianism, *Ga. Univ. Mag.*, Mar.
1856. Classics *vs.* Mathematics, *Ga. Univ. Mag.*, June.
Gulf-Stream Agency in the Formation of Florida, Am. Assoc. Adv. Sci., *Proc.*, 10, Part ii. : 103.
1857. Geology in a Course of Education, Inaug. Address.
Three Lectures on Coal, Smithson. Inst., *Rep.*, p. 119.
1858. Morphology and Its Connection with Fine Art, *So. Pres. R.*
1859. Correlation of Forces and Conservation of Force in Vital Phenomena, Am. Assoc. Adv. Sci., *Proc.*, 13 : 187.
Same, *Am. Jour. Sci.*, 78 : 305.
Same, with Stewart, B., Conservation of Energy, p. 169.
Formation of Continents, Theory of, *Canadian Nat.*, 4.
Principles of a Liberal Education, *So. Pres. R.*
1860. Female Education, *So. Pres. R.*
Scientific Relation of Sociology to Biology.
1861. School, the College and the University, *So. Pres. R.*
1863. Nature and Uses of Art.
1866. Artificial Production of Sex, *Nashv. Jour. Med. and Surg.*, 1 : 296.
1867. Same, *Nashv. Jour. Med. and Surg.*, 2 : 332.
1869. Binocular Vision, Phenomena of :
1. Adjustments of the Eye, *Amer. Jour. Sci.*, 97 : 68.
2. Rotation of the Eye on the Optic Axis in Convergence, *Am. Jour. Sci.*, 97 : 153.
3. On the Horopter, *Am. Jour. Sci.*, 97 : 168.
1871. Binocular Vision, Phenomena of :
4. New Mode of Representing Visual Phenomena, *Am. Jour. Sci.*, 101 : 33.
On an Optical Illusion, *Phil. Mag.*, 4th Series, 41 : 266.
5. Stereoscopic Phenomena, *Am. Jour. Sci.*, 102 : 1.
6. So-called Images of Illusion, *Am. Jour. Sci.*, 102 : 315, 417.
Law of Circulation in Nature, Calif. Teachers' Inst., *Rep.*
1872. Les Images d'Illusion et la Théorie du Relief Binoculaire, *Archives des Sci.*, 41 : 394.
Earthquakes, *Univ. of Calif. Echo.*
Formation of Greater Inequalities of Earth's Surface, Theory of, *Am. Jour. Sci.*, 104 : 345, 460.
1873. Agassiz Memorial Address, Calif. Acad. Sci., *Proc.*, 5 : 230.
Ancient Glaciers of the Sierra Nevada. No. 1, *Am. Jour. Sci.*, 105 : 325.
Correlation of Vital with Physical and Chemical Forces, *Pop. Sci. Mo.*, 4 : 156.
Flight of Birds : Poising, *Nature*, 9 : 5.
Formation of Greater Inequalities of Earth's Surface. Answer to Sterry Hunt's Criticism, *Am. Jour Sci.*, 105 : 448.
Religion and Science.

1874. Great Lava Flood of the Northwest and Structure and Age of the Cascade Mountains, *Am. Jour. Sci.*, 107 : 167, 259.

1875. Ancient Glaciers of the Sierra Nevada:

2. Lake Valley Glacier, *Am. Jour. Sci.*, 110 : 126.

Binocular Vision, Phenomena of:

7. Position of the Eyes in Sleepiness, *Am. Jour. Sci.*, 109 : 159.

8. In Binocular Vision the Law of Corresponding Points may be Opposed to the Law of Direction, *Am. Jour. Sci.*, 109 : 164.

9. Comparative Physiology of Binocular Vision, *Am. Jour. Sci.*, 109 : 168.

Instinct and Intelligence, *Pop. Sci. Mo.*, 7 : 653.

Rate of Growth in Corals, *Am. Jour. Sci.*, 110 : 34.

1876. Evidences of Horizontal Crushing in the Formation of the Coast Range of California, *Am. Jour. Sci.*, 111 : 297.

1877. Binocular Phenomena Observed by Prof. Nipher, *Am. Jour. Sci.*, 113 : 252.

Binocular Vision, Phenomena of:

10. Structure of Crystalline Lens and Its Relation to Periscopism, *Am. Jour. Sci.*, 114 : 191.

Critical Periods in the History of the Earth and Their Relation to Evolution and on the Quaternary at Such a Period, *Am. Jour. Sci.*, 114 : 99.

Evolution in Relation to Materialism, *Chit Chat Club.*

Prairie Mounds, *Nature*, 15 : 530.

Wallace's Distribution of Species, *Bulletin*, Jan. 20.

1878. Binocular Relief, Theory of, *Phil. Mag.*, 5th Series, 5 : 27.

Elements of Geology. Illus.

Geological Climate and Time, *Nature*, 18 : 668.

Glycogenic Function of the Liver. No. 1, *Am. Jour. Sci.*, 115 : 99.

Man's Place in Nature, *Princ. R.*, N. S., 2 : 776.

Science and Mental Improvement, *Pop. Sci. Mo.*, 13 : 96.

Structure and Origin of Mountains, with Special Reference to Some Objections to Contractional Theory, *Am. Jour. Sci.*, 116 : 95.

1879. Genesis of Sex, *Pop. Sci. Mo.*, 16 : 167.

Scientific Relation of Sociology to Biology, *Pop. Sci. Mo.*, 14 : 325, 425.

Volcanoes about Lake Mono and Their Relation to the Glacial Drift, *Am. Jour. Sci.*, 118 : 35.

1880. Binocular Vision, Phenomena of:

11. Laws of Ocular Motion, *Am. Jour. Sci.*, 120 : 83.

Coral Reefs and Islands, *Nature*, 22 : 558.

Effect of Mixture of Races on Human Progress, *Berkeley Q.*, 1 : 81.

Genesis of Sex, *Revue Scientifique.*

Glycogenic Function of the Liver. No. 2, *Am. Jour. Sci.*, 119 : 25.

Old River-Beds of California, *Am. Jour. Sci.*, 119 : 176.

School, the College and the University, *Princ. R.*, N. S., 5 : 177.

1881. Comte's Classification of Sciences, *Berkeley Q.*, 2 : 97.

Devolution, *Occident.*

Drowning, to Prevent, by Floating, *Nature*, 24 : 260.

Evolution in Relation to Materialism, *Princ. R.*, N. S., 7 : 149.

Geology of California, in Phelps, A., *Contemp. Biog.*, 1 : 290.

Illustrations of a Law of Evolution of Thought, *Princ. R.*, N. S., 8 : 373.

Sight: Principles of Monocular and Binocular Vision. Illus.

Mr. Wallace's Island Life, *Californian*, 3 : 485.

1882. Denudation, Rate of, *Geol. Mag.*, 9 : 288.
Higher Utilities of Science, *Californian*, 5 : 306.
Judd on Volcanoes, Notice of, *Californian*, 5 : 85.
Mineral-Vein Formation Now in Progress at Sulphur Bank, *Am. Jour. Sci.*, 124 : 23.

1883. Carson Foot-Prints, Calif. Acad. Sci., *Bull.*
Same, *Nature*, 28 : 101.
Also in *Independent* and *Occident.*
Domestic Ducks that Fly Abroad Like Pigeons, *Sci.*, 1 : 249.
Genesis of Metalliferous Veins, *Am. Jour. Sci.*, 126 : 1.
Mineral-Vein Formation at Steamboat Springs, Nevada, *Am. Jour. Sci.*, 125 : 424.
Movement of the Arms in Walking, *Sci.*, 1 : 220.
Mutual Relation of Intellectual and Moral Culture, *Overland*, 2d ser., 1 : 10.
Reefs, Keys and Peninsula of Florida, *Sci.*, 2 : 764.
Science and Literature, *Overland*, 2d ser., 1 Feb. ; suppl., p. 8.
Wright's "Religion and Science," Review of, *Sci.*, 1 : 543.
Continent-Formation, *Geol. Mag.*, 2d Series, 10 : 523.

1884. Carrying Power of Fluid Currents, *Pop. Sci. Mo.*, 24 : 555.
Compend of Geology for High Schools.
Elevation and Subsidence of Earth-Crust, *Nature*, 29 : 212.
Fiske's "Excursions of an Evolutionist," Review of, *Overland*, 2d ser., 3 : 329.
Guyot's "Creation," Review of, *Sci.*, 3 : 599.
Optical Phenomena : Phantom Images, *Sci.*, 3 : 404.
Pressure of Currents, *Mining Record*, 16 : 341.
Psychical Relation of Man to Animals, *Princ. R.*, N. S., 13 : 236.
Right-Sidedness : Letter on Deflection in Walking, *Nature*, 29 : 452.
Same (contin.), *Nature*, 30 : 76.
United States Geological Survey, Review of 2d and 3d Reports of, *Sci.*, 4 : 62.

1885. Earthquake Shocks More Violent on the Surface, *Sci.*, 6 : 540.
General Principles of Art and Their Application to the Novel, *Overland*, 2d ser., 5 : 337.
Immortality in Modern Thought, *Sci.*, 6 : 126.
Relations of Berkeley to Modern Religious Thought, *Berkeleyan.*
Royce's "Religious Aspects of Philosophy," Review of, *Overland*, 2d ser., 5 : 542.
Shad Propagation on the Atlantic Coast, Result of, *Sci.*, 6 : 520.
Warren's "Paradise Found," Review of, *Sci.*, 5 : 406.

1886. "Louis Agassiz, His Life and Correspondence," Review of, *Overland*, 2d ser., 7 : 103.
Double Vision, *Sci.*, 7 : 506.
Fiske's "Darwinism and Other Essays," Review of, *Overland*, 2d ser., 7 : 334.
Germ of Hydrophobia, *Sci.*, 8 : 102.
Glycogenic Function of the Liver, *Am. Nat.*, 20, pt. 1 : 473.
Inherited Polydactylism, *Sci.*, 8 : 166.
Permanence of Continents and Ocean-Basins and Development of North American Continent, *Geol. Mag.*, 3d Series, 3 : 97, 287, 288.

Pharyngeal Respiratory Movements of Adult Amphibia under Water, *Sci.*, 7 : 462.

Post-Tertiary Elevation of the Sierra Nevada, Shown by the River-Beds, *Am. Jour. Sci.*, 132 : 167.

1887. Binocular Vision, Phenomena of :

12. Phantom Images Formed by Binocular Combination of Regular Figures, *Am. Jour. Sci.*, 134 : 97.

Depth of Earthquake Focus, *Sci.*, 10 : 22.

Flora of the Coast Islands of California in Relation to Recent Changes of Physical Geography, Calif. Acad. Sci., *Bull.* No. 8 : 515.

Same, *Am. Jour. Sci.*, 134 : 457.

Relation of Agassiz to the Theory of Evolution, *Pop. Sci. Mo.*, 32 : 17.

Relation of Biology to Sociology, *Berkeleyan*, 23 : 123.

Relation of Evolution to Religious Thought. (Pamphlet.)

Sense-Training and Hand-Training in the Public Schools, *Educ. Jour.*, Mar.

Sound-Blindness, *Sci.*, 10 : 312.

Star Rays or Rays Streaming from Light, *Sci.*, 9 : 14.

What is Evolution? *Pop. Sci. Mo.*, 31 : 721.

1888. Binocular Vision: Experiments in Vision, Answer to Hyslop, *Sci.*, 11 : 252.

Evolution, Difficulty in, *Pop. Sci. Mo.*, 33 : 125.

Evolution and Its Relation to Religious Thought.

Glacial Motion, *Philosoph. Mag.*, 25 : 452.

Hark's "The Unity of Truth," Review of, *Pop. Sci. Mo.*, 33 : 699.

Human Beings as Pack-Animals, *Sci.*, 11 : 290.

Monocular Vision, *Sci.*, 11 : 119.

Mountain Formation, *Philosoph. Mag.*, 25 : 450.

Problem of a Flying-Machine, *Pop. Sci. Mo.*, 34 : 69.

Relation of Evolution to Materialism, *Pop. Sci. Mo.*, 33 : 79.

Significance of Sex, *Sci.*, 11 : 229.

Transfer of the Lick Observatory to the University. (Pamphlet.)

1889. General Interior Condition of the Earth, *Am. Geol.*, 4 : 38.

Origin of Normal Faults and the Structure of the Basin Region, *Am. Jour. Sci.*, 138 : 257.

Ptomaines and Leucomaines and Their Relation to Disease, *Pac. Med. Jour.*, Sept.

Same, *Sci.*, 14 : 322.

South Revisited, *Overland*, 2d ser., 14 : 22.

1890. A Curious Visual Phenomenon, *Am. Jour. Psychol.*, 3 : 364.

Elements of Geology. New ed.

Evolution and Its Relation to Religious Thought. New ed.

Rev. Howard MacQueary's "Evolution of Man and of Christianity," Review of, *Overland*, 2d ser., 16 : 110.

Natural Grounds of Belief in Personal Immortality, *Andover R.*, 14 : 1.

1891. Evolution and Human Progress, *Open Court*, 5 : 2779.

Factors of Evolution, Their Grades, and the Order of Their Introduction, *Monist*, 1 : 321.

Mutual Relations of Land Elevation and Ice Accumulation During the Quaternary, Geol. Soc. Am., *Bull.*, 2 : 329.

Origin of Organic Forms: Answer to Keep, *Overland*, 2d series, 18 : 198.

Plato's Doctrine of the Soul Compared with that Derived from the Study of Nature, Phil. Union, *Bull.*

Relation of the Church to Modern Scientific Thought, *Andover R.*, 16 : 1.

Tertiary and Post-Tertiary Changes of the Atlantic and Pacific Coasts, Geol. Soc. Am., *Bull.*, 2 : 323.

1892. Race Problem in the South, in "Man and the State," 349.

Relation of Philosophy to Psychology and Physiology, *Phil. Soc. of Wash.*, Dec.

1893. Estimated Distance of Phantoms, *Sci.*, 21 : 333.

Evolution and Human Progress, *Pacific Coast Teacher.*

Main Characteristics of University Education, *Berkeleyan.*

Theories of the Origin of Mountain Ranges, *Jour. of Geol.*, 1 : 543.

Same, Am. Assoc. Adv. Sci., *Proc.*, 42 : 1.

Same, *Nature*, 48 : 551.

1894. Elements of Geology. 3d ed.

Evolution and Its Relation to Religious Thought. 2d ed.

John Le Conte, Memoir of, *National Acad. Sci.*, 3 : 369.

New Lights on the Problem of Flying, *Pop. Sci. Mo.*, 44 : 744.

Posepny's "Genesis of Ore-Deposits"; Criticisms, Am. Inst. Min. Eng., *Trans.*, 24 : 996.

1895. Are Consequences Ever a Test of Truth? *Sci.*, N. S., 2 : 379.

Causes of the Gulf-Stream, *Sci.*, N. S., 2 : 188.

Critical Periods in the History of the Earth, *Am. Geol.*, 16 : 317.

Same, Univ. of Calif., *Geol. Dept. Bull.*

James Dwight Dana, Memoir of, Geol. Soc. Am., *Bull.*, 7 : 461.

Dana's "Manual of Geology," Review of, *Sci.*, N. S., 1 : 548.

Effect of Theory of Evolution on Education, *Educ. R.*, 10 : 121.

Elements of Geology. Rev. and enl. Pl. Illus.

Erect Vision and Single Vision, *Sci.*, N. S., 2 : 629.

Erect Vision, A Last Word on, *Sci.*, N. S., 2 : 850.

Evolution and Social Progress, *Monist*, 5 : 481.

Evolutional Idealism, *Philos. Union Leaflet.*

Geikie's "Memoir of Sir Andrew Crombie Ramsay," Review of, *Sci.*, N. S., 1 : 490.

Inverted Image Once More, *Sci.*, N. S., 2 : 667.

Nature of Vowels, *Sci.*, N. S., 2 : 189.

Prof. Royce's Address, "Conception of God," Remarks on.

1896. From Animal to Man, *Monist*, 6 : 356.

Honors to James Hall at Buffalo, *Sci.*, N. S., 4 : 698.

1897. Prof. Cattell's Review of "Sight," *Sci.*, N. S., 6 : 737.

Cerebral Light, *Sci.*, N. S., 6 : 257.

Co-operation of Religion and Science in Uplifting Humanity, Unit. Club, Addresses.

Earth-Crust Movements and Their Causes, Geol. Soc. Am., *Bull.*, 8 : 113.

Same, *Sci.*, N. S., 5 : 321.

Relation of Biology to Philosophy, *Arena*, 17 : 549.

1898. Don's Work on Auriferous Veins, Am. Inst. Min. Eng., *Trans*, 27 : 993.

Geological Classification and Nomenclature, Symposium on, *Jour. Geol.*, 6 : 337.

Optical Illusion of a Rotating Fan, *Sci.*, N. S., 8 : 480.

Origin of Transverse Mountain Valleys and Some Glacial Phenomena in Those of the Sierra, *Univ. Chronicle*, 1 : 479.

True Idea of a University, *Univ. Chronicle*, 1 : 3.
Windmill Illusion, *Sci.*, N. S., 8 : 480.
1899. Cerebral Light Again: Answer to Professor Scripture, *Sci.*, N. S. 10 : 58.
Ozarkian and its Significance in Theoretical Geology, *Jour. Geol.*, 7 : 525.
1900. Century of Geology, *Pop. Sci. Mo.*, 56 : 431, 546.
Comparative Physiology and Morphology of Animals.
Journal of Ramblings in the High Sierra, Sierra Club, *Bull.*, 3 : 1.
Kingsley's Criticism on Outline of Comparative Physiology and Morphology: Answer, *Sci.*, N. S., 11 : 909.
Religious Significance of Science, *Monist*, 10 : 161.
1901. The Larynx as an Instrument of Music, *Sci.*, N. S., 13 : 790.
What is Life? *Sci.*, N. S., 13 : 991.

Experiments with Bromo-Cyanogen on Southern Gold-Ores.

BY S. H. BROCKUNIER, WHEELING, W. VA.

(Mexican Meeting, November, 1901.)

DURING the examination of a gold-property in Georgia, last summer, I had occasion to study the effect of different chemicals upon the ore; the object being to find a more economical method of extraction than chlorination, as practiced there, had proved to be. Some of my notes and results may be of interest to others.

The country-rock consists of mica-schist, hornblende-schist and black slate. The vein-matter is quartzite and schist, containing some stringers of quartz, the whole forming a body from 20 to 50 ft. wide. All of the rocks in the vicinity have become disintegrated to a depth of from 50 to 75 ft., forming the so-called saprolite.

I found the workings to represent two distinct classes:

I. Open-cut surface-ore: very soft, oxidized and disintegrated; containing much alumina, silica and iron. Average value, $4 per ton.

II. Ore from lower levels: quartzites and schist; very hard; containing much silica and manganese, some alumina, and from 2 to 10 per cent. of pyrites. Average value, $8 per ton.

Class I. was soon dismissed. The only way to make it pay would have been by the use of steam-shovels and a large crushing-plant. The tendency to slime would be the principal difficulty.

Class II. presented an interesting study. The values seemed to cling closely to the sulphurets; yet, while little or no gold was visible to the eye, it was almost always possible to obtain colors by panning. The gold so obtained was always very finely divided.

The stamp-mill was started as nearly like its previous working as possible, in order to observe and correct its faults. The old method of 4-in. drop, 4-in. discharge, 100 drops per minute, 35-mesh screen, no inside plates and 5 stamps to one vanner was not at all satisfactory. We almost immediately shut down 20 stamps, put all the vanners on the other 20, increased the drop to 6 and the discharge to 7 in., decreased the number of drops to 90, and changed the screen to 40-mesh. This gave better amalgamation, and we were able to use inside plates; but at the best we could only save 20 per cent. of the value of the ore by amalgamation.

The mine-ore was concentrated 20 tons into one, at a cost of $1 per ton of concentrates, which were hauled to the chlorination-plant for treatment. I understand that this plant was erected from specifications of the well-known Thies process. It consists of two 40-ft. single-floor reverberatory furnaces, two 4-ton chlorination-barrels and a full equipment of filters, precipitation-tanks, etc.

Laboratory-tests had shown that the ore was difficult to roast, and that the extraction would not be high; nevertheless we made a fair test of the plant, with the following results:

TABLE I.—*Cost of Roasting One Ton per Furnace per 24 Hours.*

Labor,	$2.40	
Wood,	1.20	
		$3.60
(Decided loss of gold by volatilization.)		
Cost of treatment per ton, chemicals, labor, etc.,	$2.50	
Total cost per ton of concentrates,		$6.10

The extraction was from 60 to 70 per cent., which, on $12 roasted concentrates, meant $8.40, obtained at a cost of $6.10. The additional cost of mining, milling, concentrating and hauling being considered, it was clearly a losing business.

Experiments were now begun in two directions: (1) the classification, and (2) the chemical treatment, of the pulp from

the stamps. These were afterwards combined, so that the experimental plant consisted of three tanks, each 6 ft. in diameter, 4 ft. deep, and placed so that the overflow passed from the first into the second, and from the second into the third. The pulp from the stamps entered the first tank, and was there kept agitated by a current of air through perforated pipes in the bottom of the tank. The heavier particles settled in this tank. The second was merely a settling-tank, where the middlings sank through still water, allowing the slimes and finest particles in suspension to overflow into the third tank. These slimes were caught in the third tank by a perforated false bottom which was overlaid by a filter-bed of cheese-cloth, matting, and charcoal.

TABLE II.—*Results in Classifying Surface Oxidized Ore.*

65 per cent.	settled in	first tank ;	assay-value	per ton,	. .	$6.80
34	"	" second "	"	"	. .	4.00
1	"	" third "	"	"	. .	4.40

TABLE III.—*Results in Classifying Unoxidized Mine-Ore.*

35 per cent.	settled in	first tank ;	assay-value	per ton,	. .	$8.00
63.5	"	" second "	"	"	. .	12.00
1.5	"	" third "	"	"	. .	6.00

These results were rather surprising; because we had been told that the quantity of slimes was much larger, and that the principal values lay in them. Our tank-system clearly disproved this, because all the gangue was caught. That the values were not in the slimes was further confirmed by experiments on a canvas-table.

Laboratory-tests with "straight" cyanide, upon unroasted ore, showed an extraction of 40 to 60 per cent. of the gold, but with large consumption of cyanide, which was partially, but not effectually, remedied by a preliminary alkaline wash. With roasted ores, an extraction of 80 per cent. was secured; but the loss of cyanide was still too large.

We then undertook a series of experiments with bromo-cyanogen of varying strengths; and the final results were entirely satisfactory.

We made our bromo-cyanogen by the following reaction:

$$5NaBr + 16HCl + K_2Mn_2O_8 + 5KCy + H_2O = 5BrCy + 2MnCl_2 + 5NaCl + 7KCl + 9H_2O.$$

Notes.

Care was taken to have final solution slightly alkaline.

Our first attempts to make the bromo-cyanogen in this way were not successful, hydrolysis of the cyanide occurring, and ammonia being formed.

It would have been cheaper to use KBr; but it was not available at the time.

Other oxidizing agents and acids were tried; but the best results were obtained by above method.

One and one-third ton of mine-ore, assaying $6.80 gold per ton, was taken for our first trial; there was, therefore, $9.06 in gold to be extracted. The ore was treated in the first tank, where it had been separated in our tank-experiments. One-third of a ton of bromo-cyanogen solution was run on, the original strength of which was: KCy = 0.07 per cent.; KCyBr = 0.10 per cent.

TABLE IV.—*Results of Treatment with* KCyBr *Solution.*

Time.	Milligrammes of Au per A.T.	Extraction. Per cent.	Strength of KCy. Per cent.
At beginning, ...	......	......	0.07
After 3 hours, ...	0.22	16.0	0.05
" 16 "	0.24	17.9	0.027
" 24 "	1.14	83.8	0.025
" 30 "	0.56	41.0	0.005
" 48 "	0.28	16.9	0.0006

The pulp was stirred by air before each sample was taken. Assays of the gangue during the treatment showed that the loss of values in the solution during the leaching was by precipitation, and experiments were therefore undertaken to discover the cause and remedy.

The same amount and grade of ore treated with plain cyanide (strength, 0.147 per cent.) showed an extraction of only 10.93 per cent. in 42 hours, and a loss of 75 per cent. of cyanide. The effect of air forced through KCyBr solution was investigated; but it caused no such great loss of cyanide as is shown in these tests. With roasted ore and KCyBr solution we obtained a 60 per cent. extraction, but at the cost of large consumption of cyanide.

Treating ore with preliminary alkaline wash decreased the consumption of cyanide, but lessened the percentage of extraction. We finally gave the ore both an acid and an alkaline wash, and obtained following result:

Two tons of ore treated, assaying $8 per ton, therefore $16 in gold to be extracted.

1. Preliminary wash of dilute H_2SO_4 (1 part acid to 300 to 500 parts water): contact one hour.

2. Wash of plain water.

3. Alkaline wash of KOH, in this case, 2 lbs. KOH to 1–2 ton water (determined by titration): contact one hour.

4. One-half ton KCyBr solution run on (strength of KCy 0.33 and of KCyBr 0.30 per cent.).

TABLE V.—*Results of* KCyBr *Treatment after Acid and Alkaline Washes.*

Time.	Milligrammes of Au per A. T. of Sol.	Extraction. Per cent.	Strength of KCy. Per cent.
At beginning,	......	......	0.33
After 30 minutes,	......	......	0.33
" 5 hours,	0.55	33.8	0.32
" 8 "	0.56	35.0	0.32
" 24 "	0.75	47.0	0.31
" 36 "	1.00	62.5	......
" 45 "	1.10	69.2	0.30

Our extraction, therefore, was $11.07 gross, or $5.53 per ton from our $8 ore. To this add the 20 per cent. extracted by the stamps, and we have a total extraction from the raw ore of 75.3 per cent. From $10 ore (which was the value of the ore under discussion before treatment by the stamps), we therefore obtained $7.53 per ton. The cost of this process for mining, milling and treatment, under a fair estimate, was $5 per ton, leaving a net profit of $2.53 per ton.

We think that the extraction from raw ore can be raised to 85 per cent., and that, with a large plant specially constructed, the cost can be much reduced.

It was found by blowing the slimes out that, by this arrangement of tanks, the resulting ore could be treated directly in the tanks without subsequent handling, merely diverting the pulp coming from the stamps to a second series of tanks while the first series was being treated. In our work, the third tank was merely a safeguard, as in none of our tests did values in it run high enough for treatment. We used the air introduced into the bottom of the tanks to stir the pulp at regular intervals, and found it more thorough and economical than hand-labor.

Exhaustive experiments are contemplated to decide more exactly about the preliminary washes, to determine the adapta-

bility of electrolytic precipitation to this process, and to enlarge the plant.

I am convinced that the future of gold-mining in the South, and perhaps in some other sections, depends upon this or some similar process for the extraction of values, rather than upon the methods heretofore pursued.

Acknowledgments are due to Messrs. Charles I. Auer and John H. Bower, who materially assisted in these experiments.

The Detection and Estimation of Small Quantities of Gold and Silver.

BY LUTHER WAGONER, SAN FRANCISCO, CAL.

(Mexican Meeting, November, 1901.)

For a number of years I have, at odd times, tried to perfect a method of assay sufficiently delicate to find and estimate minute quantities of gold and silver. The object in view was to examine rocks remote from veins or mineral areas, in order to test the probability of the lateral-secretion theory. Having succeeded in measuring approximately the amount of gold and silver contained in one cubic centimeter of sea-water, I present a detailed account of the method employed, with some of the results obtained.

General Method of Assay.

The use of purified lead without other flux, blowpipe methods, extraction by cyanide, and measurement of the beads by the microscope.

Purified Lead.

The method of testing is by cupellation. On a properly prepared cupel, it is easy to cupel and find a bead of 0.002 mm. diameter. Such a bead of silver weighs about $\frac{1}{24,000,000}$ part of a milligramme. A bead 0.02 mm. in diameter weighs about $\frac{1}{24,000}$ mg., and a close approximation can be made to its weight. It is desirable that the lead used in the assay should be low in silver so as to avoid large correction, but as the parted

gold requires cupellation with lead it is essential to have the lead used of high purity. I have found the following method to give the best results of a number tried: Dissolve 500 grammes of sugar of lead in 1250 c.c. of water. Place in the center of the beaker a carbon rod for anode, and near the side a 4 by 9 in. lead plate for cathode. Attach one cell of a dry battery and leave it a week. The difference of potential in favor of the deposition of lead is about 0.1 volt; a small amount of lead is deposited which assays much higher in silver than the sample. The battery is disconnected and the solution is allowed to stand in contact with the electrodes for two months. It is then filtered and crystallized and preserved for use. Some of the crystals are ignited in a clean, iron spoon and the mixture of lead and oxides of lead is kept for use in the work. A portion of the calcined lead is reduced before the blowpipe on coal without flux; a part of the resulting metal is set aside as a source of pure lead, and the other part is assayed. The assays showed the lead to contain $\frac{1}{21,300,000}$ of silver, as a mean of several trials. By fusing any of the ordinary re-agents with this lead and cupelling, a notable increase of silver is found. This is especially true for all sodium salts, cyanides and ferrocyanides, and in a lesser degree for the mineral acids, lime, barium and borax—boracic acid being the only re-agent tested that did not show an increase of silver. A sample of Mercks C. P. carb. sod. (10 molecules H_2O) showed over 3 grammes Ag per ton. A sample of KCN gave per metric ton 2605 milligrammes of silver and 147 of gold. This was a mean of several tests, and this sample was used in the assays reported below.

Measurement.

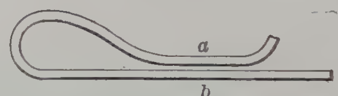
A microscope having powers of 40 and 60 diameters has in the eye-piece a micrometer ruled on glass. With the power of 40, one division is 0.02873 mm. With the power of 60, one division is 0.02001 mm. The latter is practically the same as a division on the ivory scale used in quantitative blowpipe-work. For careful work, both powers are used and a mean of the readings is taken. Thus, if a bead read 7.35 on the 60, it should read 5.12 on the 40. Using sunlight and reading the greatest diameter of the shadow of the bead, will usually per-

mit readings to be made to .001 mm. or one-twentieth of a scale-division.

The Form and Weight of Beads.

The form of a bead is the resultant of three forces, namely, gravity and the surface-tensions of the metal and the litharge respectively. Experience has shown that if the cupellation be done in a uniform way, the beads will show a constant mutual relation of diameter, base and height. For small beads, under

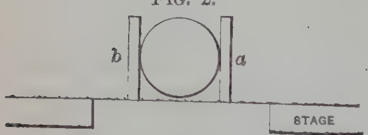
FIG. 1.



Watch-Spring Clip for Measuring Assay-Beads.

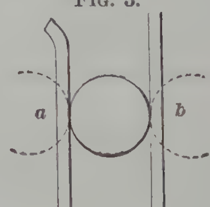
0.5 mm. in diameter, the action of gravity is much smaller than that of the other forces; hence, the beads tend to approach a spherical form, and for ordinary purposes it is sufficient to measure the diameter only, without removing from the cupel. Concerning this weight, there is much confusion: thus, in Cornwall's *Plattner* the weight of a silver bead 1 mm. in diameter (No. 50 on the ivory scale) is said to be 3.48 mg. A few pages beyond is a table giving the weight of a similar bead (but

FIG. 2.



Vertical Section, Showing Bead in Clip (Fig. 1).

FIG. 3.



Plan, Showing Bead in Clip (Fig. 1).

measured in a jaw-micrometer) at 6.12 mg. A monograph by J. S. Curtis (6th report of the U. S. Geological Survey) gives a table for beads measured by cross-hairs and a micrometer-stage, and based upon perfect sphericity at zero, with a decrease of 20 per cent. for a bead 0.409 mm. in diameter, and an interpolated formula to satisfy these conditions. To test the matter, I devised a clip made of a small watch-spring, as shown in Fig. 1, which is about full size. The inside at *a*, *b*, is polished for

0.25 in. The bead is cleaned and inserted between the jaws of the clip, the base of the bead resting on b, slightly nearer the top than the bottom. The clip is placed on the stage and lighted from below. It should present an appearance like Figs. 2 and 3. The polished steel reflects the image and gives a sharp line, very helpful in measuring diameter, base and height.

A number of gold beads, varying in diameter between 0.1 and 3.3 mm., were separately weighed, and also measured in the clip above described for diameter (B) of base, diameter (D) of bead, and height (H) of bead. In order to deduce the volume from these measurements, the height (h) of the missing segment must be known. This cannot be directly measured; but an expression can be found, giving the volume of the bead as a fraction of the imaginary completed figure.

FIG. 4.

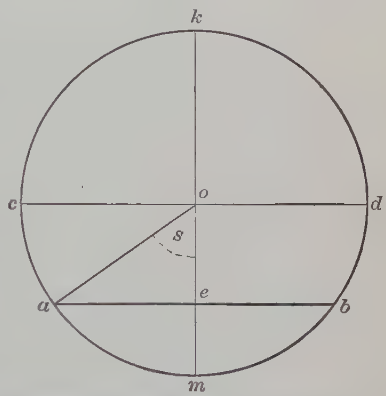


Diagram Illustrating Calculation of Weight of Bead from Measurements.

In Fig. 4, $ab = B$; $cd = D$; $ko + oe = H$, and amb is the segment cut off. Assuming the completed figure to be a sphere, $ko = om = co = od = oa = R$, or radius of the sphere; and from inspection of the diagram it is clear that $\frac{ab}{cd} = \sin. S$ (S being the angle aoe); and that $ko + oe = H = R + R \cos. S$.

The volume of the segment of a sphere, divided by the volume of the sphere, is

$$3 \sin.^4 \frac{S}{2} - 2 \sin.^6 \frac{S}{2}.$$

Calling this fraction P, the volume of the bead $ackdb$ can be expressed as $(1 - P)$ vol. of sphere, on the assumption that the completed figure *is* a sphere. But this would never be the case theoretically, and seldom practically (*i.e.*, within the limits of practicable accuracy for the calculation here under consideration), for the obvious reason that the effect of gravity, and possibly of other forces, upon the liquid bead must distort it from a perfectly spherical shape. In other words, km in Fig. 4

could seldom be safely assumed as equal to *cd*. Another factor must therefore be introduced to correct the error due to this lack of sphericity. In Fig. 4,

$$km = \frac{cd}{ke} H = \frac{2}{1 + \cos. S} H.$$

Denoting by Q the coefficient of H in this expression, we have, as the final expression for the volume of the bead,

$$(1 - P) Q \frac{\pi}{6} D^2 H.$$

The measurements being in millimeters, it is only necessary to multiply this volume by the specific gravity in order to obtain the weight of the bead.

A number of beads weighed on a good balance 73.27 mgs. The same beads calculated by the above formula measured 72.61 mgs. One bead of silver weighing 92 mgs. measured 91.463 mgs. Sin. S will not vary much if care be taken not to touch the bead with the tip of the flame after it sets. In gold buttons the usual effect is to increase H and diminish D, thus giving too small a value, if only D is read.

For beads too small to allow easy manipulation the measurements are best made upon the cupel. For such work, where the scale-division is 0.02001 mm., the value used is

$$\begin{aligned} &\text{Weight} = D^3 \times 0.00007598 \text{ for gold (log.} = 5.8807) \\ &\text{and} \qquad\; D^3 \times 0.00004213 \text{ for silver (log.} = 5.6246). \end{aligned}$$

This agrees with the value given by Curtis for silver where the diameter = 0.08 mm.

(D in the above formula is the number of scale-divisions of 0.02001 mm. each.)

The above constants were used in the reduction of all the tests tabulated in this paper.

Fine Cupellation.

Take elutriated bone-ash and grind it very fine in the agate mortar, heat to redness and preserve in a bottle. For the fine cupellation press in, lightly, ordinary bone-ash; heat it to expel moisture; then cover evenly with the fine ash and burnish with

the smooth end of the agate-pestle; heat carefully, and, before placing the bead upon it, examine for cracks with a good lens. The cupel-surface should be smooth and polished. The bead of lead should not weigh more than 8 to 10 mg. and should be clean. As soon as fused, the bead should be kept moving. When it gets too small to be seen, the stain of litharge on the cupel shows its *locus*. Care must be taken not to overheat near the finish. By carefully observing the above directions 1 mg. of assayer's lead will show a small bead of silver. (Suppose the lead to contain 0.1 oz. of silver per ton; then 1 mg. will give a bead of 0.43 division or 0.0086 mm. diameter.)

Should the assay be for silver only, the cupel is placed upon the stage of the microscope and the diameter of the button is read; or, if it is large enough to handle, it can be detached, placed in the clip, and the three dimensions measured for volume of gold and silver.

Parting.

The diameter of the alloy is read and estimated as silver, after which it is parted as follows: Procure a supply of clear white cups or saucers of a cheap grade, which should be free from dark specks, and which should stand the heat to be used, without cracking or losing the assay; break into pieces about 15 mm. square and cement a piece with sealing-wax to a strip of tin plate for a handle, placing the concave side uppermost. Clean the surface of the porcelain with nitric acid and wash it, leaving a drop of water on it. Place the cupel near it, and with the aid of a lens and chisel-pointed needle detach the bead. With a fine splinter of wood, previously wetted, touch the bead, and transfer it to the drop of water. Should the bead be too small for a hand-lens, take a fine needle; amalgamate the point with sodium amalgam; and, having the bead in focus on the stage, touch it with the point of the needle. Sufficient mercury will adhere to render the bead visible; and it can then be treated like a larger bead. With a capillary tube or dropper, add nitric acid very cautiously, warming the assay until the silver is seen to blacken and dissolve slowly. The gold will remain in a coherent mass. With a strip of filter-paper remove the acid; add strong acid, and warm again, after which the assay is washed sweet, and dried. With small amounts of gold great care must be taken to have a clean white surface to

work upon, and dust must be kept away; otherwise, it will be difficult to see and recognize the speck of gold.

Some of the calcined purified lead is reduced without flux on coal and kept in a clean box for use. Cut from it a small piece of 2 to 3 mg. weight; flatten it with the agate-pestle and turn up a corner for a handle. With the forceps cover the speck of gold and gently press down the lead. Next heat the corners of the porcelain before the blowpipe, carefully working inward to the test, and fuse the latter; after which, scorify the bead over the area covered by the lead when laid on, and cool. The bead detaches easily and with a clean bottom. Examine the bead with the lens to see that it is clean, and cupel as before directed. As gold will stand a high heat, it is advisable to measure, and, if there is any irregularity, reheat to melting point.

By observing the above directions, I have made beads which I estimated at $\frac{1}{10}$ of a scale-division. The bead was perfect in form and color, and with higher powers could easily have been measured with much precision. Such a bead is calculated as follows, according to the formula, weight $= D^3 \times 0.0000759$; D being 0.1 of a scale-division:

Log D = 0.1, ...	9.0000
	3
Log D^3, ...	7.0000
Log constant, 0.0000759, ...	5.8807
Log weight, ...	2.8807

$$\text{Weight} = 0.0000000759 \text{ mg.} = \frac{1}{13,100,000} \text{ mg.}$$

It is readily seen that we have here a method at once simple and delicate for detecting the presence and estimating the amount of the precious metals.

The Probable Error.

As previously stated, the diameter of the bead can be read to 0.001 mm. Calling this the error, and taking the weight as KD^3 (K being a coefficient) and its differential as $3KD^2$ (.001), we have as the per cent. of error:

$$\frac{3KD^2(0.001)}{W} = \frac{3KD^2(0.001)}{KD^3} = \frac{0.003}{D}.$$

The following table shows the weight of gold beads and the probable error:

Weight, mg.	Error, per cent.	Weight, mg.	Error, per cent.
0.1,	1.36	0.001,	6.36
0.01,	2.95	0.0001,	13.69

Cupellation Loss.

A sample of about 331 mgs. of assayers' sheet-lead, cut into small squares, mixed and cupelled, gave a bead covering 6 divisions, or .12 mm. in diameter. A sample of 41 mgs. gave a bead covering 3 divisions; and one of 5.2 mgs. a bead of 1.5 divisions; thus proving that there is no sensible departure in the proportion of loss for small beads from that of larger ones. Hence, in what follows, I have deducted the silver due to the lead cupelled and called the remainder the true amount.

Cyanide Assays.

A sample of cyanide of potassium was tested by evaporating 2 grammes with 10 c.c. of water and 6 grammes of calcined lead. The dried mass was fused on a clean coal, and the resultant lead was weighed, cupelled, and the button parted. The value found as a mean of several trials was: silver, 2.605 grammes, and gold, 0.147 grammes, per metric ton. A 1-per-cent. solution was made and kept for use. The general method was to take 40 grammes of finely pulverized material, with 10 c.c. of KCN solution (= 100 mgs. KCN) and 50 c.c. of distilled water; place all in a flask and shake well, repeating the shaking at intervals for one or two days; then filter on a dry filter into a graduated vessel; note the c.c. used for assay; transfer to an evaporating dish; add 400 mgs. of calcined lead, and evaporate. The residue was then fused on a clean coal, the lead being weighed and cupelled, and the button parted, as above described.

This assay is made more certain by heating the coarsely pulverized rock to redness, quenching in water, evaporating to dryness, and then pulverizing, taking a sample for assay and grinding it in an agate mortar to a fine mud, and using a cyanide solution of one-third per cent., after which, the whole is transferred to a flask and made up to the desired weight of cyanide solution. The weighed sample of ore is triturated

with only sufficient cyanide-solution for the purpose of proper grinding. When it is transferred, as above described, to a tared flask, the pestle, mortar and funnel are washed into the flask with either cyanide solution or water. It is desirable to have a known weight or volume of cyanide solution in the flask, because it will be filtered upon a dry filter, and usually some aliquot part of the original solution will be assayed. Ore can be pulverized finer in this way than by the dry method. The assay is usually made alkaline by this treatment,—a result which is beneficial for cyanide work.

Assay of Sea-Water.

I have long thought that the sea-water was the chief source of gold and silver, and that some effort should be made to ascertain the facts and thus know what are the chances that the sedimentary rocks have been impregnated with small amounts of gold and silver. I have verified the statement of Sonnstadt that a small portion of $BaCl_2$ will throw down a portion of the gold; also the statement of Dr. Don that heating the salts to redness and redissolving and assaying the residue would recover most of the gold. I have also evaporated to dryness, and find that after dissolving in water the residue carries a notable amount of gold and silver; also evaporating, or rather boiling with calcined lead acetate, fixes a larger amount of silver and some gold. The highest results were had by evaporating 1 to 10 c.c. of sea-water with 200 mgs. of lead per c.c., and fusing on coal, but the results were not concordant nor uniform, probably due to difference in heating and to volatilization of the silver. The gold was tolerably constant by this method; 500 c.c. were evaporated to dryness, redissolved in a minimum of water, and while boiling a 2-per-cent. solution of $BaCl_2$ was added drop by drop to slight excess and again evaporated to dryness. The salts were heated to a bright red for ten minutes and redissolved and filtered; the ppt. of barium sulphate and some lime were placed in a flask with some water and a drop of phenolphthalein. It required 4 drops of lime-water to produce a permanent color showing alkalinity. The solution was made up to 25 c.c. containing 40 mgs. of KCN, and shaken at intervals for a day—filtered and washed and the filtrate evaporated with 400 mgs. of lead, and the assay made as described. There were two assays made, which showed as follows:

Cyanide Method.

Found per metric ton of water:

	Gold, . . .	10.9 mgs.	Silver, . . .	165 mgs.
	" . . .	11.3 "	" . . .	174 "
Mean	" . . .	11.1 "	" . . .	169.5 "

A portion of the filtrate containing the chlorides was then assayed directly with lead, which gave for Ag 1010, 1241 and 1164 mgs. per ton. The three beads were then cupelled together and parted. There was a small bead of gold estimated at 1.5 mgs. per ton; from which I conclude that the amount present in this sample was of gold 12.6 mgs. and of silver not less than 1.500 grms. per ton. Dividing by .02756, the amount of salts in the sample, it becomes,

Per metric ton of salts:

Gold, . . . 457 mgs.,	Silver, . . . 54.4 grams,

and for normal sea water, containing 3.5 per cent. of salts, gold, 16.0 mgs.; silver, 1.9 grms. (NOTE.—Several tests showed a much higher value for the silver.)

Sea weed and floating organic matter were tested by washing sweet, calcining and cyanide. In some cases large amounts of silver were found. Samples of the bay mud taken from the dredges gave from 3 to 18 cents in gold per ton. A sample of mud from Islais Creek channel, which is very foul from sewage, gave a very high assay in silver. Samples of organic matter taken near sewer outlets always assayed higher in silver than samples taken at more remote points.

As a result of the numerous tests made, I think it can be safely affirmed that organic matter reduces some silver from the sea water and probably some gold. The latter cannot be positively known, because the gold may have been carried in suspension and have become attached to the object assayed; but the method described might be used to examine organic matter taken at a point free from coastal influence. Personally my views, based upon my work done, are that the sediments as deposited are enriched by the reducing action of organic matter, and that the newly-formed stratum of mud contains not only the gold and silver due to the water present, but also some additional amount reduced by the organic matter.

Assays of Rocks.

The statement of Dr. Don that country-rocks can be assayed by panning down a quantity and assaying the residue, has been tested, as well as the statement that pyrite must be present in order to find gold; and my experiments show that both statements are incorrect, or, at least, not in accord with my experience.

I have found that grinding poor quartz ore in an agate mortar to a fine slime, and removing the slime by water from time to time, is a very delicate test for gold. Most of the samples assayed and tabulated below were thus tested, and showed no gold. The method used for most of the samples was to crush to 60-mesh sieve and take 40 to 50 grms. of ore, and 60 c.c. of water containing 100 mgs. of KC. The stoppered bottle containing the assay was well shaken at intervals for a day or two, filtered on a dry filter, and the filtrate measured, and then evaporated with 400 mgs. of calcined lead acetate, and fused on coal b.b., as described. In these assays there are but two fluxes added, the lead and the cyanide; and as both have their tenor known, great confidence can be placed in the result. As an example, take No. (10), sample of Carrara, Italy, marble: Weight taken, 45 grms. + 60 c.c. water + 100 mgs. KC; time, 2 days; take 42 c.c. of solution for assay. Weight of Pb reduced 340 mgs.

Diameter of	Ag Au	bead,	5.45	divisions	=	0.109 mm.
"	" Au	"	1.55	"	=	0.031 "

Calculation.

Log., 340 mgs., . .	2.5315	
Log., 21,300,000 mgs., .	7.3284	
0.000016, . .	5.2031	the weight of the silver in the lead.

As the cupellation loss is greater, it is disregarded.

Log., 5.45, . . .	0.7364	
	3	
	2.2092	
Constant, ...	5.6246	
0.00682, ...	7.8338	the weight of Ag Au calculated as Ag.

Log., 1.55, . . .	= 0.1903		
	3		
	0.5709		
Constant, ...	= 5.8807		
0.000283, ...	= 6.4516	the weight of Au found.	
Ag. in 70 mgs. cyanide, .	= 0.00018		
Au found, . . .	= 0.000283		
	0.000463		
Ag Au found, . . .	= 0.006820		
Ag in 31.5 grms., . .	= 0.006357	log.	= 7.8032
Log., 31.5, . . .			= 1.4997
Ag, per grm., . . .			= 6.3035
Add 6 for one metric ton,			= 2.3035
= 201 mgs. silver per metric ton.			
Au found, ...	= 0.000283		
Au in 70 mgs. cyanide, .	= 0.0000103		
Au. in 31.5 grms. ore, .	= 0.0002727	log.	= 6.4357
Log., 31.5, .			= 1.4997
			4.9360
Add 6 for one metric ton,	= 8.63 mgs.,		= 0.9360

Extracted from Carrara Marble.

Gold, ...	8.63 mgs.	per metric ton.
Silver, ...	201.00 "	

The following table comprises results of assays of rocks taken remote from veins or known regions of mineral values. The results are reported in milligrams per 1000 kilograms of ore assayed:

1. Granite. Porcupine Flat near Lake Tenaya, Cal., Au, 104; Ag, 7660.
2. Granite from Lake Tenaya, Cal., Au, 137; Ag, 1220.
3. Granite, headwaters American river, Cal., Au, 115; Ag, 940.
4. Syenite, Candelaria, Nevada, Au, 720; Ag, 15,430.
5. Granite, Candelaria, Nevada, Au, 1130; Ag, 5590.
6. Sandstone, Colusa county, Cal., sample from Hayward Building, Au, 39; Ag, 540.
7. Sandstone from quarry, Angel Island, Cal., Au, 24; Ag, 450.
8. Sandstone, Russian Hill, San Francisco, Cal., Au, 21; Ag, 320.

9. Marble, Columbia quarry, Tuolumne county, Cal., Au, 5; Ag, 212.

10. Marble, Carrara, Italy, Au, 8.63; Ag, 201.

11. Basalt, Paving block, from Petaluma, Cal., Au, 26; Ag, 547.

12. Diabase, Mariposa county, Cal., Au, 76; Ag, 7440.

From the above assays it is seen that the average silver is about 20 times that of the gold, or, excluding Nos. 4 and 5, the ratio is about 30 to 1, and this high ratio tends to confirm the belief that the gold and silver were deposited with the rock and have since remained with it. Assuming that the water has an underground circulation, then the source of the gold and silver can be found in the country-rocks, and we need not go to the unknown regions below for a source of supply. It should be remarked that the above assays by cyanide do not purport to be the value of the rocks but only of the amount extracted. Some check work on one of the samples showed 20 per cent. more by calcining and grinding to a fine mud. I have also found the above methods useful in cyanide tests, notably in experimental work for testing the rate of solution; from a definite amount of solution 1 to 5 c.c. is taken, and either evaporated with lead or the gold is precipitated by $AgNO_3$, and the precipitate reduced and parted, and estimated as above. The method of course requires some calculation for the amounts subtracted from time to time; but, on the other hand, it is all from the same sample. Much valuable information can be rapidly gained from a few well-chosen tests of this kind.

The method is of great value in tests in regions remote from assay offices. One gram of properly prepared sample treated either by direct fusion or a larger amount amalgamated, and direct fusion of 0.5 gram will closely check the ordinary fire assay on ores as low as .2 oz. Au per ton.

Acknowledgments are due to Mr. H. W. Turner, U. S. Geological Survey, for specimens furnished for assay, and to Mr. Newton M. Bell, of San Francisco, for the use of his laboratory and assistance rendered during the investigation.

James F. Lewis.

Biographical Notice of James F. Lewis.

BY R. W. RAYMOND, NEW YORK CITY.

(Mexican Meeting, November, 1901.)

It would be unjust to these *Transactions*, as well as to the subject of this notice, if the death of one whose professional enthusiasm, executive ability, noble character and winning personality have contributed so much to the profit and enjoyment of his innumerable acquaintances (that is to say, *friends*), and to the success of the American Institute of Mining Engineers, should pass without special recognition of his service and merit. At the time of Mr. Lewis's death, July, 1901, I was not willing to wait until the November meeting in Mexico, before publishing my personal tribute to my dear friend of many years. Nor was I willing, on the other hand, to forego the privilege (which I felt myself almost ready to claim as a right) of contributing to our *Transactions* this Biographical Notice of one of the dwindling group of those early members of the Institute, by whose devotion, courage and wisdom the foundations of its prosperity were laid, and its rapid, yet solid, progress was inspired and guided.

I therefore published in *The Engineering and Mining Journal* of August 3, 1901, the article which (with some trifling changes and additions) is here repeated. The excellent portrait of Mr. Lewis, engraved to accompany that article, has been kindly placed at my disposal for this notice by the publishers.

James Frederick Lewis was born at Blandford, Mass., May 26, 1840, and died at Boston, July 22, 1901. Of the 61 years between these dates more than 40 were spent in ceaseless, energetic and useful work.

He was educated at Blandford, where he lived until he was about 14, and subsequently at Meriden, Conn., and Bloomfield, N. J. At the outbreak of the Civil War, upon the first call for volunteers, he enlisted as a private in the 3d Connecticut regiment, and at the battle of Bull Run received a wound which led to his discharge from service. In 1862 he married, and

subsequently moved to Westfield, Mass., near the place of his birth, where, about 1875, he formed, with the two brothers Rand, who had succeeded to the business of their father, the firm of Rand, Lewis & Rand, manufacturers of whips. I have no particulars covering this enterprise, but from what I know of the methods of business at that period in New England, when manufacturing and peddling went hand-in-hand, and from what everybody knows concerning the energy and tact of Mr. Lewis, it is safe to infer that he made all New England acquainted with the merits of the goods furnished by his firm, and showed the world how a man could sell whips, who never needed the whip himself!

About 1876 he became superintendent of the brown-hematite mines of the Manhattan Mining Company, near Amenia, N. Y. Into this new occupation he carried the methods of careful business management, not at that time so common as now in mining operations. He classified all expenditures for materials and labor under numerous sub-headings, so that he was able to compare one year with another, as to the cost of any given item. Realizing the importance to the profession of exchanging information on such matters, and at the same time obeying the dictates of prudence as to the publication of business details, he devised the form of statement illustrated in his paper,* read at Philadelphia in 1878, which exhibits for each of three years the cost of each item in the operation of the Amenia mines—not in money, but in its percentage of the total operating expense. This method was afterwards adopted by other contributors to the *Transactions* of the Institute, and is to be recommended as an excellent contrivance for communicating professional experience without giving away business secrets.

The brown-hematite mines east of the Hudson river supplied, for the most part, the charcoal blast-furnaces of the same region, and the charcoal-iron industry was already declining, by reason of the exhaustion of its fuel resources, the increased expense of mining, and the reduced value of charcoal-iron, through the substitution of cheaper material for many purposes to which it alone had formerly been deemed suitable. Not even such management as Mr. Lewis's could contend long against fate. One after another the charcoal blast-furnaces went out of blast, and

* *Trans.*, vi., 172.

the mines became idle. In 1881 Mr. Lewis accepted the superintendency of the coke blast-furnace of the Pennsylvania & Virginia Coal and Iron Company, at Quinnemont, West Va., and the Grace furnace of the same company, near Staunton, Va. Here he developed again his characteristic energy and vigilance of administration, and his capacity of converting business acquaintances into personal friends.

But his former Massachusetts partners had not forgotten him; and early in 1884 they called him into the service of the Rand Drill Company, which had already become one of the leading American concerns manufacturing power-drills. His wide acquaintance among mining men in both the North and the South, coupled with his geniality, tact and intelligence, soon made itself felt in a great extension of the business of the company, and, about 1892, it was found advisable to establish in Chicago a branch, of which Mr. Lewis was placed in charge. His management of this department compassed not only the great tributary mining fields of Michigan, the Mississippi Valley, and the farther West, but also a considerable business in Canada. In 1890 the Canadian Rand Drill Company had been organized for the purpose of manufacturing, as well as selling, the drills, compressors, etc., required by the mines of Canada from British Columbia to Cape Breton. Of this new company Mr. Lewis was the president, and about three years ago he took up his residence in Canada, where the present admirable shops of the company at Sherbrooke, in the Province of Quebec, were designed by him and erected under his constant supervision. Nothing could better illustrate the confidence placed in his fairness and judgment by all who knew him than the circumstance that the new ministry, which came into power in Canada shortly after he went to Sherbrooke, and which was theoretically opposed to protective tariffs, listened with candor to Mr. Lewis's representations concerning the business effect of the proposed abolition of duties, recognized their justice and their moderation, and finally, braving the charge of political inconsistency made by the opposition, adopted into their governmental scheme, and carried through the legislature of the Dominion, the features which he had advocated as just and wise.

The tireless energy and vigilance which he had shown in other fields were abundantly exhibited in this new enterprise.

As one of his assistants recently informed me, nothing that was going on in the way of new construction or the filling of important orders was allowed to escape his frequent personal inspection. Even after the beginning of what was practically his last illness he used to insist on driving to the shops, and seeing "what the boys were doing." This triumph of a vigorous will over bodily weakness was all the more remarkable because the insidious malady (Bright's disease) which ultimately caused his death is one which commonly impairs bodily energy and imperatively forces abstention from labor. His health, previously robust, had been impaired by one long illness, some years before he took up his residence at Sherbrooke; and for the last two years of his life he was fighting a losing battle with death. Yet at the meeting of the Institute in Nova Scotia, in August and September, 1900, he met his friends and colleagues with the old hopeful, genial, vigorous air, and displayed, as chairman of the Canadian General Committee of Reception, the old executive force and skill. And again to the Richmond meeting, in February last, though wasted already in bodily vigor, he brought the well-known and well-beloved victorious spirit. Not long after, while temporarily in Boston, he suffered an attack of acute pneumonia, so severe that it was impossible to remove him from the hotel in which, after a brave resistance, and indeed after beating off the new enemy, he succumbed to the older one. Only a day or two before the end he was planning to return to work again. His frigate went down as a gallant captain's should do, with flag flying and batteries firing to the last. For he was, not only by profession, but also by conviction and life, serving under a Commander from Whom alone he would take final orders, and Who had bidden him never to give up the ship.

Mr. Lewis became a member of the Institute in 1875. His formal contributions to the *Transactions* were few, but valuable, as the following list shows:

"The Hematite-Ore Mines and Blast-Furnaces East of the Hudson River" (*Trans.*, v., 216);

"Memorandum Showing the Different Expense-Accounts in Mining Hematite Ore at the Manhattan Mine, Sharon Station, N. Y." (*Trans.*, vi., 172);

"Biographical Notice of J. F. Holloway" (*Trans.*, xxvi., 827);

"The Chicago Main Drainage-Channel" (*Trans.*, xxvii., 288).

But his real contributions to the Institute comprised much affectionate interest, thought and labor, not represented in written essays. He was a manager in 1879, 1880 and 1881, and a vice-president in 1886 and 1887, and again in 1895 and 1896.

There are many members still living, thank God! though so many have passed on, who can remember the Amenia meeting of 1877, of which Lewis was the leading spirit. The account of the excursions and entertainments of that meeting, beginning on page 16 of Vol. VI. of the *Transactions*, comprises an outline of four days' travel in special trains, over numerous intersecting main and branch-railroads, with intercalated episodes of mountain-climbing, carriage-drives (in conveyances for which levy had been laid upon the whole region for miles around), picnics, train-lunches *en route*, banquets, etc.—all carried out without a dollar of expense to the members of the large party. Even to-day, after a long period of similar experiences in all parts of the United States and Canada, as well as in Mexico, the Amenia meeting remains a model of liberal entertainment and perfect organization and management. The complications involved in the railroad-trips alone can be realized only by those who have undertaken to make cross-country railroad-connections in Connecticut. Moreover, it was (with the exception of the scantily attended Boston meeting of 1873) the first Institute meeting in New England, and it was necessary not only to plan the arrangements, but to gain the co-operation of companies, firms and individual citizens not yet familiar with the importance of the Institute. All this was done by Mr. Lewis; and now, looking back upon almost innumerable examples of splendid welcomes and entertainments, I think it fair to say that James F. Lewis led the way and set the pace. The *Proceedings* of the same meeting show that he found time also to contribute to its professional profit, as well as to provide thoroughly for its social pleasures. And in this double spirit he labored for it, unwearied, to the end, repeating at the Virginia meeting of 1883, the Chicago meeting of 1893, and the Nova Scotia meeting of 1899, the exhibition of his skill, energy, devotion, and technical and executive ability.

I name these occasions particularly, because they involved great responsibility and labor on his part in the position (formal or actual) of executive manager of the local arrangements. But at innumerable other meetings, in the labors of which

he was not obliged to share, he made it his delightful duty to be present, counting as a misfortune anything which prevented him from attending them—accompanied by his wife, who shared his affection for the Institute, and now, from a lonely and sorrowful home, bids me convey, to his brethren and hers, her thanks for the abundant sympathy which they have shown to her in her great bereavement.

Mr. Lewis's characteristic feeling of good fellowship and brotherly love is illustrated by a list of the Associations, technical and social, of which he was a member. This list reads as follows: American Institute of Mining Engineers; American Society of Mechanical Engineers; American Society of Civil Engineers (Associate); Iron and Steel Institute, London; Foundrymen's Association, Chicago; Technical Club, Chicago; Field Columbian Museum, Chicago; Art Museum, Chicago; Historical Society, Chicago; Western Society of Engineers, Chicago; Western Railway Club, Chicago; St. Louis Railway Club, St. Louis; Mining Society of Nova Scotia; Lafayette Post, G. A. R., New York; Republican Club, New York; Twilight Club, New York; New England Society, New York; Halifax Club, Halifax; City Club, Halifax; St. George's Club, Sherbrooke, P. Q.

In every one of these associations he was a welcome, congenial and useful factor; but I cannot believe that in any of them he was more widely known or more heartily appreciated than in the Institute of Mining Engineers, which ranked him among the veterans, esteemed and beloved, of the days of its youthful prime.

His tender and sympathetic biographical notice of J. F. Holloway (*Transactions*, Volume XXVI., page 827) closes with the words:

"We bid him an affectionate farewell, as he departs to join those brethren of his and ours whom he used to recall with such glowing praise. He goes to a meeting of good fellows, who found one another out while they were in the flesh. And, some day, we who remain shall get our notice, and journey to a glad reunion —with Holley and Coxe and Holloway on the Reception Committee."

That committee, like many another in the earthly history of the Institute, may well rejoice, in its higher sphere, to find itself reinforced by the brave, bright, helpful presence and power of James Frederick Lewis!

Gold-Mining in the Transvaal, South Africa.

BY JOHN HAYS HAMMOND, NEW YORK CITY.

(Richmond Meeting, February, 1901).

The Transvaal comprises about 120,000 square miles (nearly the size of the United States Territory of New Mexico).

Besides the famous Witwatersrand, which will here be described in detail, there are two quartz-mining districts of some importance, viz., Lydenburg and De Kaap.

The Lydenburg district first attracted attention in 1876, when the alluvial deposits of that section began to be exploited. At a later period vein-mining was started, and at the present time several companies are operating in that district. The product in 1898 of five companies, running 137 stamps, was 154,560 tons of ore, yielding 108,884 crude ounces of gold (an average of 14.09 dwt. crude gold per ton) valued at £392,378.

The De Kaap gold-fields were discovered in 1884. In 1898, seven companies, running 200 stamps, produced 89,760 crude ounces of gold, valued at £314,792.

I. Mining Titles in the Transvaal.

The mining laws of the Transvaal are most excellent in character, and while the claims cover every square foot of land for an area of nearly 40 miles long by from 2 to 3 miles wide, there have been practically no conflicts over extra-lateral rights.

Notwithstanding the change in the political status of the Transvaal likely to follow the present war, it may be confidently assumed that the main features of the mining law of the South African Republic will be retained, and certain oppressive features of monopolies, etc., bearing with special weight on the mining industry, will be abolished. The dynamite monopoly was one that bore most heavily on the mining industry; and, according to the Reports of the State Mining Engineer, explosives, including fuse and detonators, amounted to nearly 10 per cent. of the total working costs of the mines. Furthermore, it was impossible to obtain the proper quality for the most economical working, and often 30 per-cent. or 40-per-cent. gelatine had to be used in many instances where 60-per-cent.

gelatine would have been much cheaper. These, indeed, form no part of the mining law proper—that is, the law regulating the tenure of mining titles. It is to be expected, both in the nature of the case and in view of the declarations already made by British statesmen, that the "ancient laws and customs" of the Transvaal will be retained under British rule, as far as possible. At all events, the principles of the English common law and the immemorial precedents of English practice will undoubtedly require the determination of present rights according to the status in force at the time of their inception. The mine-operators of the Transvaal whose titles were acquired from the Republic will therefore be secured in the position thus defined; and hence it is not inappropriate in this place to state the Transvaal mining law as it existed prior to the present war.

According to that law, the right of mining for and disposing of all precious metals and precious stones belongs to the State; but the State President, with the advice and consent of the executive council, may, by proclamation, throw open government ground as a public diggings, upon which mining claims can be "pegged off" (*i.e.*, located) as specified by law.

An owner of a farm may, upon application to the government, have the farm likewise proclaimed. Before the proclamation of a private farm, the owner has the right of allotting to any person or persons he may specify a certain number of claims, called *Vergunning* claims, the number depending upon the size of the farm, but not exceeding 60 as a maximum.

The owner has the further right to reserve for himself one-tenth of the ground, which is called a *Mynpacht*. This portion is held by the owner as a lessee, under what is called a *Mynpacht Brief*, for a term of not less than 5 years, nor more than 20 years, with the privilege of renewal. The rental on *Mynpacht* is 10*s*. per *Morgen* (2.11 acres).

He may also retain a certain area for residential and farming purposes, called a "*Werf*" or homestead. Finally, the owner of a proclaimed farm is entitled to one-half of all licenses paid to the government.

A reef-claim (lode-claim) is 150 Cape ft. (155 English ft.) on the strike of the reef by 400 Cape ft. (413.2 English ft.) in the direction of the dip—about 1.47 acres.

TABLE I.—*South African Land-Measures.*

1 Cape ft. .	=	1.033 English ft.
1 Cape sq. ft.	=	1.067 English sq. ft.
1 Claim .	=	150 by 400 Cape ft. = 60,000 Cape sq. ft. or 64,025 English sq. ft. = 1.47 English acres.
1 Morgen .	=	92,196 English sq. ft. = 2.1165 English acres of 43,560 sq. ft.

Prospecting is not allowed on private ground without permission of the owner, but public ground is open to prospectors, though claims may not be pegged out until after proclamation of the ground in question as above described.

For a prospecting-license on proclaimed private ground there is a charge of 5*s.* per month per claim, half of which goes to the owner and the rest to the government. On government-ground the similar charge is 2*s.* 6*d.* per month, which goes to the government.

When, in the judgment of the mining commissioner, the results of the exploration justify the step, he may convert the prospecting licenses into a digger's license, after which a charge of 20*s.* per claim per month is made, provided ore from the property is being crushed. If, however, no ore is being extracted and crushed from the claim, the charge for the digger's license is 15*s.* per month.

In 1896 the receipts from prospecting-licenses amounted to £620,000; from diggers' licenses, £61,000, and from machine-stand licenses, £59,000.

II. GENERAL FEATURES OF THE WITWATERSRAND.

This mining district derives its name from the *Witwatersrand*, or "white-waters range," of hills immediately north of Johannesburg. These hills rise from 400 to 600 ft. above the general level of the surrounding country, have a general E. and W. trend, and constitute the watershed of this part of South Africa, their northern slope draining into the Limpopo river and thence into the Indian ocean, and their southern slope into the Orange river and thence into the Atlantic. This ridge can be traced some 40 miles, and consists of quartzites and interstratified schists.

The gold-field lies on the high plateau of the southern Transvaal. In its physical aspect the country bears a striking resemblance to certain parts of Wyoming and Nevada. While perhaps somewhat less regular in its undulations, it is equally

destitute of trees other than a sparse growth of shrubs, and in appearance suggests herding and agriculture rather than mining. It is from 4200 to 6000 ft. above sea-level, to which fact it owes its temperate and mild, salubrious climate, in spite of its semi-tropical latitude. The low-lying coastal lands contiguous to the Transvaal are, on the other hand, malarial and unhealthy.

The soil of the country is, in most localities, fertile; but irrigation is generally necessary; and this, owing to the lack of facilities for storing water, is not feasible at the present time.

The Transvaal has a rainy season of four or five months, the heavy rains commencing usually with November or December and continuing until March or April. This is what is known as the summer or warm season. The thermometer rarely reaches 95 degrees in the shade, and the heat is "dry." During the remaining "winter" months (April to September) rain is very exceptional, and there is no extreme cold. Snow is a rare occurrence in the Witwatersrand district. While the climate is remarkably salubrious and invigorating, the district has had in the past a high rate of mortality, by reason of the lack of proper sanitation. Undoubtedly this will be greatly minimized under better government.

The town of Johannesburg lies upon the southern slope, about midway between the E. and W. extremities of the "banket"-basin, immediately to the north of what is known as the central section of the Rand. This is by far the most important mining section of the gold-field. The Witwatersrand district, in a comprehensive sense, embraces also the outlying districts of Heidelberg and Klerksdorp.

Johannesburg is reached by three railway-lines, from the ports of Cape Town, Delagoa Bay and Durban, the distance by rail being 1013, 396 and 487 miles respectively. At the outbreak of the war the town contained about 75,000 whites, almost all Uitlanders (foreigners), the Boer residences being usually rural. It contained also about 25,000 blacks.

The city is well laid out, and has many fine office-buildings and residences. The handsomest of the latter are situated a mile or two from the center of the business portion of the town, along the slopes of the Witwatersrand.

III. Historical and Commercial Notes.

Mining in the Transvaal was prohibited until 1868, at which time the government, being in dire financial straits, threw open the gold-fields to exploration and exploitation by all comers, and even went so far as to offer a bonus for the discovery of profitable mines in the country. As a result, prospecting in the early '70s led to the discovery of quartz-veins and the inauguration of mining in several parts of the northern Transvaal. In 1885 the conglomerate- or "banket"-beds of the Witwatersrand were discovered. In that year a small stamp-battery was erected to crush the material of a quartz-vein, a few miles west of Johannesburg, and a crushing of conglomerate was subsequently made in this battery. But it was not until April, 1887, that a battery of three stamps was erected to treat the ore of the Witwatersrand "banket." This was followed by the erection of other batteries, and the output of gold for that year was 23,000 ounces. The product increased by leaps and bounds, as is shown by the table of production given on page 823.

1. *Financial Conditions.*

At the outbreak of the war the total capitalization of the gold-mines of the Witwatersrand was over £70,000,000 at par, and at market-prices about £147,000,000. A large part of these amounts represents worthless properties which have been "floated" during "boom" times; yet, notwithstanding this excessive capitalization, the mines yielded about 7 per cent. on the total capitalization at par, and about 3.5 per cent. on market-prices. Eliminating properties notoriously without value, and also the capitalization of certain "deep-level" properties which have not, as yet, reached a producing stage, we may pronounce the returns from *bona fide* investment and competent management to have been exceedingly satisfactory.

In 1898* seventy-seven companies operating stamp-batteries produced 4,295,609 crude oz. of gold bullion of the value of £15,141,376, and of these companies, forty-one distributed in dividends for that year £4,847,505, or about 15.6 per cent. on their nominal capital of £31,018,000. The market-capitalization of the same companies, however, was £82,555,000; and

* It need hardly be said that the statistics of 1899 and 1900 would have no value, by reason of the interruption of mining due to the war.

the dividends returned on this capitalization were about 5.9 per cent.

The majority of the "outcrop-companies"—indeed, nearly all of those situated in the central section (extending from the Langlaagte Estate to Knights, on the Witwatersrand)—are free of indebtedness, and will not require further capital, unless for future increase of plant, especially for enlarging their milling capacity. Any additional capital required for such purposes could be provided either from the profits already earned, or by the issue of debentures, to be ultimately likewise redeemed from profits.

For the "deep-level" properties, on the other hand, and especially for those covering the deeper levels,* *i.e.*, those situated on the second and third lines of claims parallel to the outcrop, a large amount of money must be expended before the mines can become productive. Instead of increasing the capital stock for this purpose, it is generally the practice of the Rand companies to raise the money by the issue of debentures. There has been no difficulty in obtaining working capital by these means, often to the extent of £400,000 or £500,000. About £5,000,000 of such debentures have been issued.

Houses of high standing have been able to raise such loans of working capital upon debentures bearing interest at 5 to 6 per cent. per annum, giving as an inducement to the purchaser the right to exchange the debentures for fully paid-up shares, at a certain price, within a given period from the date of issue, during which period the shares are likely to command a good premium.

Nearly all the Rand companies are controlled by large financial concerns, such as Wernher, Beit and Co., who control the Rand Mines group and some other properties; the Cons. Gold Fields Co., which controls the Simmer and Jack (one of the largest mines on the Rand), the Robinson Deep, the Nigel Deep, and some of the first, as well as many of the second, row of "deep-levels"; the Messrs. Farrar, who control the East Rand Proprietary and its subsidiaries, the Angelo, Dreifontein, New Comet, etc.; Barnato Bros., who control the Primrose, Glencairn, Ginsberg, Roodepoort, etc.; and A.

* A full and clear explanation of the nature and relations of the deep-level mines is given in Mr. Leggett's paper on "Deep-Level Shafts," etc., presented at the Canadian meeting of the Institute, in August, 1900. *Trans.*, xxx., 947.

Goerz and Co., who control the Geldenhuis Estate, the May Cons., the Lancaster and the Geduld Princess Estate, etc.; Mr. Neumann and associates, controlling the Cons. Main Reef, Treasury and Wolhuter; Messrs. Alba, controlling the Aurora West, Meyer and Charlton, Geo. Goch, Van Ryn, etc.; and Mr. Robinson, who controls the Robinson group, comprising the Langlaagte and Randfontein Estates and their several subsidiaries. These parties have the entire financial and technical direction of the companies in which they possess a major voting interest. All the important companies are listed on the stock exchanges of Johannesburg and London.

The financial administration of the Witwatersrand mines is, as a rule, able and honest. The Transvaal law requires a monthly statement of the amount of ore crushed, gold produced, etc. Such reports are published monthly by the companies in great detail.

TABLE II.—*Gold-Production of the District.*

	Ounces.	Value. £.	Dividends.* £.	Ratio of dividends to total gold produced.
1887,	23,125	81,042	12,510	15.4
1888,	208,122	734,477	67,653	9.2
1889, Unrecorded,	369,557 42,000	1,300,514	407,599	31.3
1890,	494,817	1,735,491	146,927	8.5
1891,	729,268	2,556,328	394,717	15.4
1892,	1,210,869	4,297,610	811,864	18.9
1893,	1,478,477	5,187,206	1,100,203	21.2
1894,	2,024,164	6,963,100	1,540,394	22.1
1895,	2,277,640	7,840,779	2,198,943	28.0
1896,	2,280,892	7,864,341	1,638,881	20.8
1897,	3,034,678	10,583,616	2,759,505	26.1
1898,	4,295,609	15,141,376	4,847,505	32.0
	18,469,218	64,285,880	15,926,701	
Jan. to Oct., 1899,† Chamber of Mines,	3,946,546			
Nov., 1899, Govt. returns,	61,780	14,273,000 (ap.)	2,933,251	20.5
	22,477,544	78,558,880	18,859,952	24.8

* There is no means of ascertaining the correct totals of dividends paid during the period from 1887 to 1891, owing to insufficient data supplied by the companies themselves.

† The production of gold in the Transvaal during 1900 was 348,760 oz., valued at £1,441,774; and for 1901 was 238,995 oz., valued at £1,014,687.

As a rule, the Johannesburg local directors and mine-managers are exceptionally trustworthy, and full reliance can be had on the accuracy of their reports. Sometimes, however, attempts are made, for market purposes, to underestimate the working-costs, by charging to capital-expenditure money which should strictly be reckoned as working-expenses. In this way fictitious profits may be shown; but the practice is not usual, and latterly has been seldom adopted.

In the formation of a new company the owner or owners of the mining-claims (and often the financial promoting syndicates) usually receive a certain number of vendors' shares of the company to be formed by an amalgamation of claims. Moreover, a certain number of shares are sold (usually at par) for working capital; and a certain number of shares are retained as a treasury reserve, which frequently are sold, sometime afterwards, at a considerable advance. The majority of the companies have greatly increased their capital since their formation; but, notwithstanding this fact, their new shares are in many cases several hundred per cent. above par.

2. *Dividends.*

The total dividends paid up to 1899 by the Witwatersrand Gold Mining Companies amount to £18,859,952. There is little doubt that within the next few years this sum will be very considerably increased. Dividends increased from £811,864 in 1892 to £4,847,505 in 1898.

Dividends and Expenses per Ton of Ore Milled.

Year.	Ore Milled. Tons.	Value per ton of ore. s.	d.	Dividends per ton. s.	d.	Expenses per ton. s.	d.
1892, . .	1,979,354	43	5	8	2	35	3
1893, . .	2,203,704	47		9	11	37	1
1894, . .	2,830,885	45	7	10	10	34	9
1895, . .	3,456,575	45	4	12	8	32	8
1896, . .	4,011,697	39	2	8	2	31	
1897, . .	5,325,355	39	9	10	4	29	5
1898, . .	7,331,446	41	3	13	2	28	1
1899,* .	6,639,355	41	3	8	11	32	4

In this calculation, to arrive at the working-costs, the dividends are deducted from the total yield of all producing mines, and the remainder is considered to be the cost of production.

* January to October.

Out of the 79 producing gold-mines in 1899 (two of which closed down in January with a joint production of only 282 ounces of gold), only 36 actually paid dividends. The high cost per ton figured out on the above basis for 1899 is due to the fact that a large amount of the profits actually earned and available for dividends was not distributed, being kept in hand to provide for extraordinary expenses expected by reason of the impending war. Even with this drastic method of calculation, the excellent showing of the mines is most remarkable.

3. *Extent of Operations.*

During 1898 there were crushed by 4765 stamps 7,331,446 tons of ore. The number of white employees was 9476, receiving an average monthly wage of £26. The native laborers numbered 88,627, receiving £2 9*s.* 9*d.* each per month, besides food and lodging. The number of stamps will be gradually increased by addition to the batteries now in use and by the erection of new batteries upon the outcrop, and, principally, upon the "deep-level" properties.

From January to October, 1899, there were milled 6,639,355 tons. From January to August of that year the average number of stamps running was 5762, the highest number at any one time being 6165. The yield of ore treated showed no change, the returns having been:—from the mills, 6.41; from tailings, 4.07; and from slimes, 2.01 dwts. of fine gold per ton. Including the returns from concentrates and by-products, the total yield per ton of ore crushed was 10.10 dwts. of the value of 41*s.* 1.3*d.*, the weight being fractionally higher, but the value exactly the same, as the year before.

The average proportion of waste sorted out was 19.71 per cent. In other words, only about one-fifth of the ore raised from the mines was rejected at the surface.

When the Companies ceased working in October, 1899, by reason of the declaration of war, the late Transvaal Government continued mining operations on its own account, upon some of the richest mines, up to May, 1900. These operations gave a yield semi-officially reported at about 490,000 ounces of fine gold, worth say £2,000,000. Particulars as to the tonnage crushed, working expenses and profits, are not obtainable. In May, 1901, crushing operations were resumed on a small scale

by the Companies themselves, 150 stamps being run at three mines. This number has steadily increased until, in December, 1901, there were 653 stamps running, representing 12 mines. During the eight months ending December, 1901, 412,006 tons of ore were milled, producing 238,995 oz. of fine gold, valued at £1,014,687, or 49*s.* 3*d.* per ton, and dividends amounting to £415,812 were paid, equal to 20*s.* 2*d.* per ton of ore milled.

In this connection, the mines may be conveniently classed in three groups: those in the outside districts of Heidelberg and Klerksdorp; those upon the main reef-series, extending easterly and westerly about 20 miles from Johannesburg as a center; and the deep-level mines of the first, second and third rows, and still deeper "deeps."

Heidelberg and Klerksdorp.—The Nigel, Rand-Nigel and Nigel Deep are at present the only producing mines in the Heidelberg district; but several other properties are being opened for future exploitation. In 1898 this district produced 34,431 oz. fine gold, worth £141,736.

So far as developed, the important mining ground in the Heidelberg district is that of the Nigel, the Nigel Deep and the Central Nigel Deep, constituting the first and second rows of deep levels below the Nigel, which is the outcrop-mine. These mines are situated about 30 miles to the southeast of Johannesburg.

In the Klerksdorp district, in 1898, five mines produced 42,962 oz. of gold, worth £177,404. These mines are situated from about 90 to 110 miles southwest of Johannesburg.

The Main Reef Series.—This is by far the most important group of mines under consideration, producing 93 per cent. of the total output. It will be further described below.

The Deep Levels.—In the Transvaal, as already observed, a mining claim consists of a parallelogram 150 Cape feet wide, extending 400 Cape feet along the dip. Mining rights are confined to the ground contained within vertical planes drawn through the boundaries of the claim, there being, fortunately for the interests of the mine-owner, no extra-lateral rights. A claim of this size is obviously too small to admit of profitable working, and therefore companies are formed by the amalgamation of a number of claims—in the case of the outcrop companies, usually 30 to 60; in the first row of deep levels 150

to 250, and in the case of the second row of deep levels a larger number still.

4. *Economic Conditions.*

In 1898 there were employed upon the Rand 9476 whites and 88,627 Kaffirs. The white laborers are predominantly British, though the leading consulting and superintending engineers, and many of the important members of the technical staffs, are Americans. The mine- and mill-foremen are usually either Americans or British subjects who have had mining experience in America. These men are generally thoroughly competent; but the average of white labor as a whole, especially among carpenters and machinists, is far below the American standard. Considerable improvement, however, is taking place in this regard. A large part of the manual laborers on the surface, and all the miners except those running machine-drills, are blacks—Basuto, Zulu, Shangani and Zambesi "boys." The quality of this black (native) labor is very poor. Most of the "boys" are utterly inexperienced when first employed; and they rarely remain long enough to acquire great proficiency. When they arrive, making in many cases tramps of several hundred miles to reach the mines, they are in an emaciated condition, and require to be "fattened up" for several weeks. After a few months' sojourn they become fine specimens physically; and, in some cases, they remain long enough at the mines to become expert miners. But it is exceptional to find great efficiency among the "boys" in drilling holes. They receive average monthly wages of £2 9*s*. and their board (which amounts to about 12*s*. per month). Their task is a hole of 3 feet per day. The holes to be drilled are located by the shift-boss, and the holes are fired by him, firing by the "boys" being usually forbidden. Some of them, however, acquire sufficient knowledge to fire a hole, and also to run a machine-drill. The latter work, however, is generally done by contract, and the contracts are given to whites.

By reason of the rapidly increasing demand for labor and the obstacles interposed by the government, there has been a great deficiency of native labor. As a result, large numbers of air-drills have been necessarily employed in stoping, to the great disadvantage of the mines, since much of the ground is of such a character as to make stoping by machine-

drills economically unadvisable. Where the reefs are flat or small, the employment of drills necessitates the breaking down of much larger blocks of ground than would be necessary with hand-drills. Moreover, work under such conditions involves the excessive use of dynamite,—an important item where dynamite is as expensive as it has been upon the Rand,—and creates at the same time an undue amount of fine waste, which not only lowers the yield of the ore in the battery, but increases the production of slimes.

The percentage of working-costs of mining is given in the subjoined table, from which may be seen that the white and the native labor represent about 30 per cent. each.

Table Showing Percentage of Working-Costs.

	Per cent.
White labor,	31.22
Native labor (including food),	29.83
Explosives (dynamite, fuse, caps),	9.70
Coal,	9.07
Chemicals (cyanides, etc.),	3.22
Tools, steel, shoes, dies, etc.,	3.29
Mining timbers, lumber,	4.05
Candles, lighting,	1.38
Sundries,	8.24
Total,	100.00

By reason of the long transportation, but especially of the excessive railway rates from Coast ports, mining-supplies are excessively high upon the Rand. As an example of the exorbitant charges of the South African railways, I quote from the evidence, given by the late Mr. L. I. Seymour in 1897 before the industrial commission of inquiry of the South African Republic, the following charges per ton-mile on the different lines named. The amounts are stated in pence :

On the Cape line, 2.34 ; the Orange Free State, 2.34 ; the Natal, 3.04 ; the Portuguese, 4.07 ; the Netherlands-Cape, 7.69 ; the Netherlands-Natal, 5.06 ; and the Netherlands-Delagoa, 4.27.

The rates for 1899, according to the legal adviser of the Johannesburg Chamber of Mines, were as follows :

Comparative Rates of Railroad Transportation in October, 1899.

Via.	Per Ton Mile. Normal.	Intermediate.	Rough Goods.
	d.	*d.*	*d.*
Cape,	2.34	1.7	1.6
Orange Free State,	2.34	1.7	1.6
Natal,	3.24	2.28	2.21
Netherlands.			
Cape and Orange Free State,	7.3	6.15	3.8
Natal,	4.74	3.8	2.8

The average local rates for normal goods on the various systems for 150 miles is as follows:

Netherlands Railroad,	6*d.* per ton-mile.
Cape "	4.3*d.* " "
Natal "	4*d.* " "

Generally speaking, the principal machinery at any time will be found to cost, erected, two and a half times its home cost.

By reason of a monopoly granted by the government to foreign concessionaires, with whom leading Transvaal officials were privately associated, the cost of dynamite has constituted about 9 per cent. of the working-expenses of the Rand mines.

The cost of coal has amounted to 8 per cent. of the working-costs. Fortunately for the mines, coal was discovered in South Africa shortly after the discovery of the gold-deposits. The principal coal-fields are from 15 to 20 miles east of Johannesburg. Coal costs about 8*s.* per ton, delivered at the pit's mouth, and the railway-rates are about 3*d.* per ton per mile.* The best quality of coal obtainable in the Transvaal has about 70 per cent. of the efficiency of Welsh coal; but the average efficiency is lower than this.

IV. Geological Features.†

The main subdivisions of South African stratigraphy, as given by Schenck‡ and Green§, are, in descending order:

* The coal rate for 1899 was 2.03*d.* on the line from Springs to Johannesburg, which represents the bulk of the coal traffic.

† Further geological details are given in *The Gold Mines of the Rand*, by Hatch and Chalmers, published by Macmillan & Co., London; *The Geological Map of the Southern Transvaal*, by Hatch, published by E. Stanford, Cockspur Street, London; and *The Witwatersrand Gold-fields, Banket and Mining Practice*, by S. J. Truscott, published by Macmillan & Co., London.

‡ *Zeitsch. d. d. Geol. Gesellsch.*, xli., 172 (1889).

§ "Geology and Physical Geography of the Cape Colony," *Quar. Jour. Geol. Soc.*, xliv., 239 (1888). This geological series is given, on the authority of both, in the book of Hatch and Chalmers, p. 10.

1. Recent formations.

2. The Karoo system, to which in *facies* the Transvaal coal-measures correspond, and which may be assigned to the lower Mesozoic of Europe. According to Becker, the coal-bearing beds of the Karoo system are Triassic, and possibly in part Permian. They are nearly horizontal, almost undisturbed, and cover the older rocks over large tracts of the country.

3. The Cape formation, the upper division of which includes the dolomite of the Transvaal and the auriferous conglomerate known as the Black Reef; the lower portion—the Table Mountain sandstone—is correlated by Hatch with the Witwatersrand conglomerate beds, and also with the conglomerate beds of Zululand and the Orange Free State.

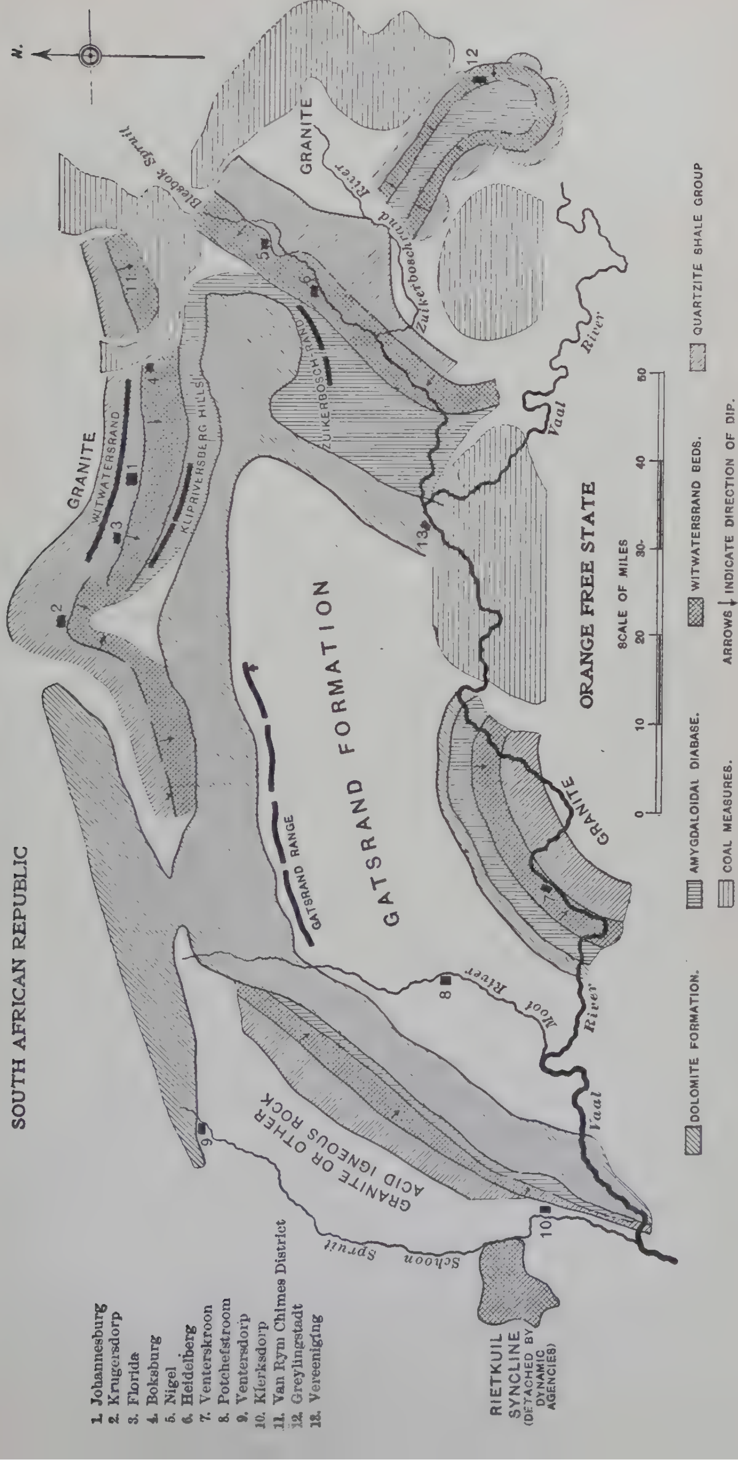
Geological Structure of the Witwatersrand Gold-Mining District.

Beginning with the granite or basement-rock of the country, and going southerly, the following formations are traversed, their stratigraphical sequence being in ascending order: 1, the quartzite-shale group; 2, the Witwatersrand beds; 3, amygdaloidal diabase; 4, the Black Reef formation; 5, the dolomite formation; 6, the Gatsrand formation; and 7, the coal-measures. Fig. 1 illustrates the relative positions of these formations.

Under granite are here included the cognate eruptive rocks, syenite, granulite and felsite, occurring in this order. In places, by reason of deformation of the granite, gneisses and schists also are found. This granitic area occurs north of Johannesburg, where the width of its outcrop is about 17 miles. It lies below, and is coextensive with the Witwatersrand syncline, presently to be described. Probably it forms, as Truscott suggests, a complete envelope over the synclines under consideration, though in many places it is obscured by later overlying formations. There are at places intrusions from this enveloping granitic mass into the younger formations.

Immediately overlying the granite area and to the south is what is known as the Quartzite-Shale group. The total horizontal thickness of this group north of Johannesburg is about 16,000 ft. In dip it varies considerably along its strike. This group extends around the Witwatersrand and the Heidelberg synclines. Auriferous conglomerates occur in this series, which,

Fig. 1.



Rough Map of the Formations Conforming to, or Found in, the Witwatersrand and Southern Heidelberg Synclines. (From Truscott's "Witwatersrand Gold-Fields.")

though persistent in strike, have been more or less patchy in character, and usually subject to considerable displacements. The Dupreez Reef series lies within this group.

Next in order come the Witwatersrand beds of quartzites, conglomerates and sandstones, lying between the quartzite-shale and the amygdaloidal diabase, and conformable in stratification with the underlying quartzite-shale group, to which they geologically belong. The width of outcrop of the Witwatersrand beds in the section through Johannesburg is about 26,000 ft., making a total thickness of the stratified rocks on the N. and S. section through Johannesburg of about 42,000 ft.

At a distance of 36,000 ft. from Johannesburg occurs the amygdaloidal diabase above mentioned, which overlies the stratified rocks, and has a thickness of about 19,000 ft. measured on the surface along this section.

Overlying the amygdaloidal diabase is the Black Reef formation, which consists of a "banket"-reef, varying in thickness from a few inches to 15 to 20 ft., together with a bed of quartzite overlying this conglomerate, and forming its hanging-wall, with a maximum thickness of about 100 ft. The average thickness of the whole Black Reef formation does not exceed 75 ft. It is regarded as later than the Witwatersrand beds, from which it is quite distinct in mineralogical character. The Black Reef conglomerate carries but a few quartz-pebbles, being composed for the most part of quartzite pebbles and shingle. It is further characterized by a high percentage of auriferous pyrites. The conglomerate is patchy in character, and has been found profitable at a few points only, where bunches of pay-ore have been worked out. At present no work is doing on this formation. Its greatest exploitation has been in Klerksdorp, where it is known as the Boshrand reef. In places it lies immediately but unconformably upon the Witwatersrand beds.

Overlying the Black Reef formation is the dolomite. This formation appears generally to be conformable in stratification with the Black Reef. It lies at a low angle of dip, being rarely steeply inclined. The dolomite south of Johannesburg has a surface-width of about 11,500 ft.

Overlying the dolomite is the Gatsrand formation, consisting of a series of quartzite and shales which, according to Truscott, occupy the axis of the Witwatersrand syncline, and form the

Gatsrand range of hills, about 12 miles south of Johannesburg. In a section from Johannesburg to Vereeniging, this formation is said to have a surface-width of about 76,000 ft. Truscott regards the stratigraphical relation of this series to the underlying dolomite as uncertain. He states that it generally appears to be conformable, though instances of unconformity occur. It dips at nearly the same angle as the dolomite; and the whole formation bears evidence of considerable alteration.

The uppermost formation is the coal-measures. It is principally developed at the E. and W. extremities of the Witwatersrand syncline, where it follows almost horizontally the other formations. According to Hatch, these coal-measures are confined to the Molteno division of the Stormburg beds, which is the uppermost member of the Karoo formation. They extend into the Orange Free State and Natal.

The Witwatersrand Conglomerate Beds.—The auriferous conglomerates occur interstratified with beds of quartzite, sandstones and schists. The schists are of several lithological varieties, but are often not of sedimentary origin, having been derived from basic igneous rocks through mineralogical and mechanical metamorphism. The horizontal thickness of the outcrop of the Witwatersrand beds is variable. In the vicinity of Johannesburg southward, it is about 26,000 ft. Assuming the average dip of the reefs at 30°, this would give a true thickness at this point of about 13,000 ft. To the north, and underlying the main reef-series, is an intrusive mass of granite, having a width at the surface north of Johannesburg of about 17 miles; while to the south, at a distance of about 3 miles, there occurs an intrusion of amygdaloid diabase, about 20,000 ft. in thickness.

There are several theories as to the origin of the Witwatersrand beds. Some geologists ascribe them to fluviatile, others to lacustrine, agencies. The majority, however, consider them to be original marginal sea-deposits, elevated through well-known geological causes to the position they now occupy. The proximate cause of this elevation was undoubtedly the intrusion of the large mass of eruptive rocks which underlies these beds. To this category belong the granitic rocks, north of Johannesburg, to which I have before alluded. The alternating strata of quartzites and conglomerates indicate alternating periods of

upheaval and subsidence of the land-mass during the period of deposition of the rock-material. In the elevation of the land-mass, anticlines and synclines were formed. The anticlines have been completely removed by subsequent erosion. Their northern limit was probably in the vicinity of the Magaliesberg range.

The outcrops of the conglomerate reefs form roughly the rim of a basin, though, by reason of faulting, there are many detached parts in the periphery of the basin; and by reason of superficial inequalities there is more or less sinuosity in its course, considerably marring its symmetry. For convenience of description, however, the term "basin" is applicable. The basin is elongated, with a longer axis of about 75 miles E. and W., and a shorter of about 25 miles N. and S. The total length of its periphery is about 300 miles. Over the greater part of this distance it had been proved by outcrops or borings, though about one-quarter is obscured by other superimposed formations. According to the shape of the basin, the conglomerate reefs dip towards a common center; *i.e.*, along the northern edge they dip southward, upon the southern edge northward, and upon the east and west edges they are west and east respectively. In their upper horizons, and at the outcrop, the reefs dip frequently as much as 80°; but in depth they are flatter, and probably at a vertical depth of 2000 ft. will have an average dip not exceeding 30°.

In the Witwatersrand there are two well-defined synclines, but the second one, known as the South Heidelberg, is limited in extent, and has no great economic importance. The above description refers to the Main Reef series, which is situated on the larger of the synclines referred to, and upon which nearly all the mining of the Witwatersrand is carried on. Several parallel series of reefs are embraced within this Main Reef series. A section in a southerly direction from the underlying granite which forms the basement rock shows, in the order of their position, the Dupreez, Main Reef, Livingston, Bird Reef, Kimberley, and Elsburg series.

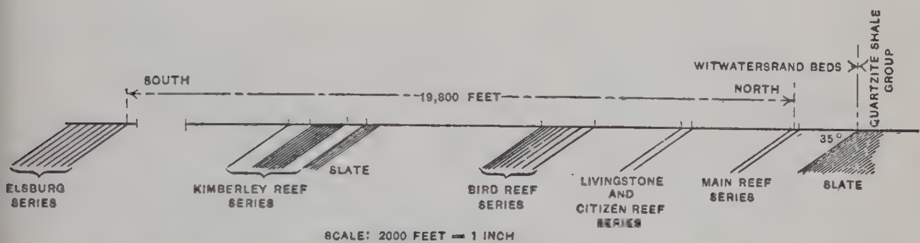
The Dupreez series, known also as the Reitfontein series, is situated about two miles north of the Main Reef. It can be traced in an easterly and westerly direction as far as the Main Reef series itself; but it has been worked successfully at but

a few points. The conglomerate beds are patchy in character, and, owing to their proximity to the underlying granite, have suffered considerable deformation.

Next in position comes the Main Reef series, which will be described in detail later on.

The most southerly series is the Elsburg, about four miles south of the Main Reef series. This is characterized by very large pebbles, averaging several inches in diameter. The intervening series (the Livingston, Bird Reef and Kimberley) are well defined and persistent, but carry so little gold as to make them unworkable, except at a few points, where small bunches of pay-ore have been found. Figs. 2, 3 and 4 (taken from Truscott's book) show the relative positions of these series (excepting the Dupreez or Reitfontein, which lies further north,

Fig. 2.



Section across Formation at Johannesburg. Projected on an Average Dip of 35°.

beyond the quartzite shale, and close to the granite) on different sections across the basin. It must be understood that these sections are mainly based, not upon actual outcrop-discoveries on section-lines, but, in many cases, upon calculations from intersections of the respective reefs in depth, and upon estimates of averages from varying underground data.

Thus Fig. 2 represents a section through Johannesburg, in which it is believed that the horizontal distances between the Main, Livingston, Bird and Kimberley series are approximately correct,—the Main–Bird interval having been determined from the positions of these two series in the Robinson Deep shafts, where the section was, so far as known, free from local disturbance, the position of the Livingston having been determined likewise on a section underground believed to be undisturbed; and the Bird–Kimberley interval having been measured on a surface-line, not found, after careful examination, to be crossed

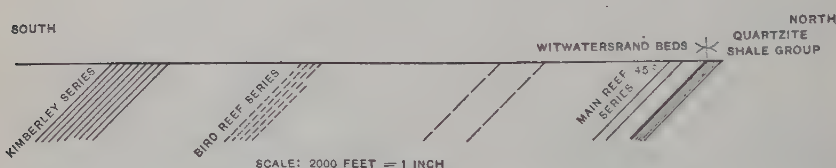
by any large dikes. The position of the Elsburg series in this section was, on the other hand, located by taking an average of the estimates of various authorities.*

Fig. 3 represents a parallel section, taken about a dozen miles E. of Johannesburg, in which the distances have been measured on the surface. It will be seen that in this region, at the E. end of the central section of the Rand, the intervals are greater and the dip is steeper.

Fig. 4 is a section across the formation taken a little west of Johannesburg, and based chiefly on surface-data. It is given here to illustrate the complicating effects of dikes and faults in this field.

These three figures taken together do not, of course, fully exhibit in detail the structural and stratigraphical features of

FIG. 3.



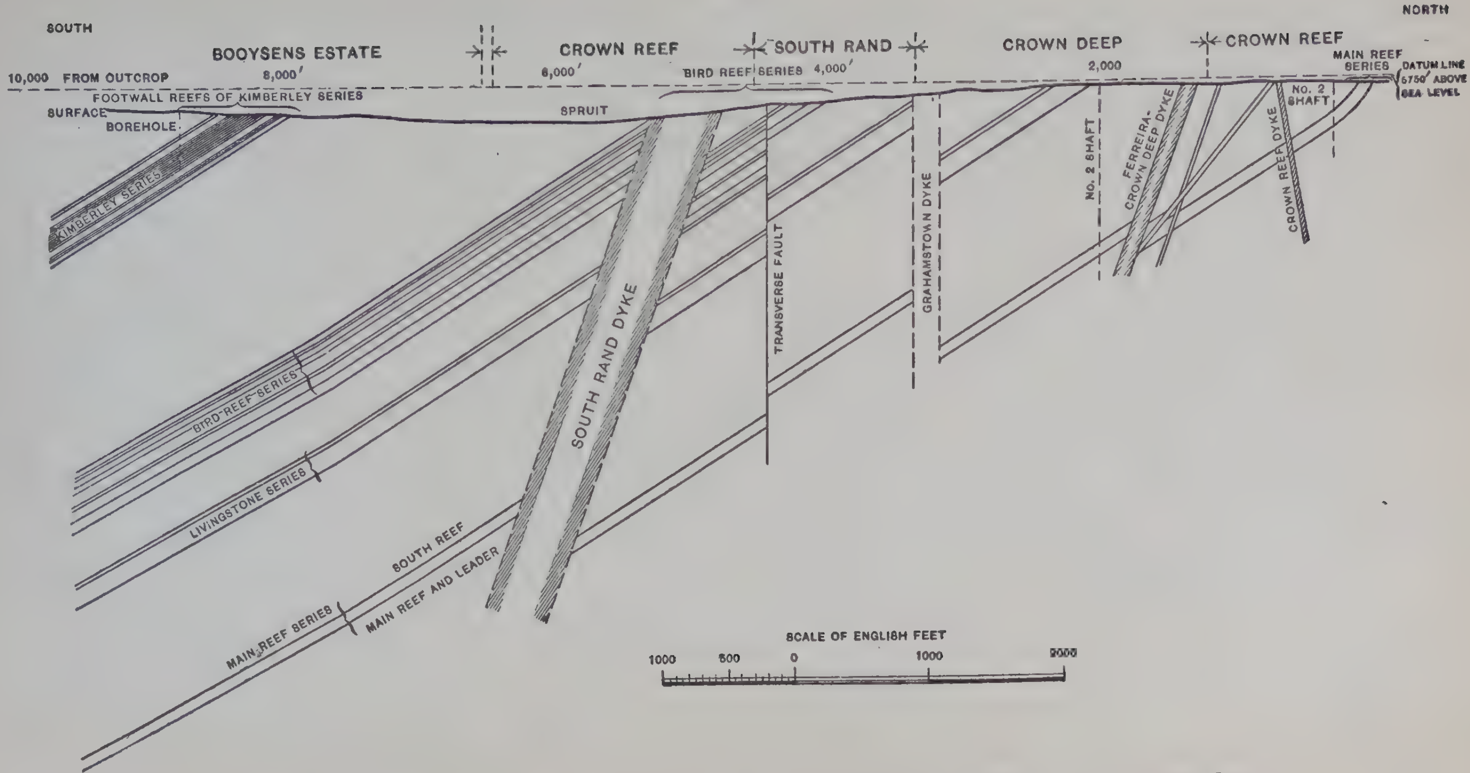
Section across Formation near Roodepoort, from Vogelstruis Estate to the Great Britain.

the Witwatersrand beds. Mr. Truscott's book, already cited, contains many other sections, which, however, it would be useless to introduce here without reproducing also his discussion of them. I have selected these three, almost at random, as furnishing hints of the nature of the problems presented to mining engineers in the planning of work in this complicated district.

The Main Reef series is situated on the southern slope of the Witwatersrand, a ridge of quartzite situated just north of the town of Johannesburg and extending in an easterly and westerly direction. This ridge has a general elevation above the country to the south of from 300 to 500 ft. It is nearly 6000 ft. above sea-level, and forms the watershed between the Atlantic and the Indian oceans.

* It will be noticed that the Kimberley–Elsburg interval is not laid out, like the rest, to scale. The break between the two, in the otherwise continuous datum-line of the section, represents more than 1200 ft.

Fig. 4.



Vertical Cross-Section, from Crown Reef on the Main Series to the Kimberley Series on the Booysens Estate.

In ascending order, the following are the most important conglomerate beds in the Main Reef series: 1, the Main Reef; 2, the Main Reef Leader; 3, the South Reef. There are several other reefs in the series; but they are generally barren, or of very low grade, and of no economic importance. While these reefs are persistent, it is nevertheless difficult to correlate them at points far apart, owing to the variations in relative position, size, gold tenor, etc. Moreover, a variable nomenclature obtains in different parts of the district, which enhances the difficulty of identification, and faulting at certain points has contributed to make correlation obscure. Along the central section of the Rand it is less difficult than at the eastern and western extremities, where authorities differ as to the proper extension of the Main Reef series.

The Main Reef, which gives its name to the series, consists generally of several beds of "banket" separated by layers of quartzite, though sometimes forming a solid body of conglomerate as much as 12 ft. in thickness. It is worked in but very few places, being of low grade, carrying rarely more than five- or six-pennyweights of gold to the ton, and on the average considerably less. Overlying this reef, separated by a few feet of quartzite in places and at times without any demarcation, is the Main Reef Leader. The pebbles of the Leader are usually larger than those of the Main Reef. In some of the mines the upper portions of the Main Reef are stoped in conjunction with the Main Reef Leader itself. The thickness of the Main Reef Leader varies from a few inches to about three feet. About 16 inches would represent the average width. In its value also it varies considerably, running from a few pennyweights to several ounces of gold per ton.

From 30 to 100 ft. or more south of the Main Reef Leader is the South Reef, varying in width from a few inches to 5 ft. Its pebbles are smaller than those of the Main Reef and the Main Reef Leader. It approaches the Main Reef in its easterly strike, and as it goes eastward, it has less economic value.*

In the Main Reef series there are sometimes as many as three "payable" parallel reefs; but while these reefs may be

* Reefs called Bastard Reefs are characterized by the occurrence of small pebbles, or where the pebbles are of ordinary size they occur sparsely distributed through the bed of quartzite. These reefs carry little or no gold.

continuous throughout a certain section, it is rare that they are all at one time "payable," the pay-ore being usually confined to two of them, and in some places to one only. The reefs vary in width from a few inches to 20 ft. or more. The combined stoping-width of the reefs worked may be stated, however, at an average of 5 or 6 ft. The matrix of the gold and the filling of the reef is chiefly well-rounded pebbles of quartz, cemented by secondary silica, and also by sesquioxide of iron and pyrites, and chloritic matter. The gold very rarely occurs in quartz-pebbles, being usually confined to the cementing material of the conglomerates. The size of the pebbles varies from a diameter of about 0.33 to 3 or sometimes 5 or 6 inches.

Beds of auriferous conglomerate similar to those of the Witwatersrand occur in the Orange Free State and in Natal, but where worked, have not as yet proved profitable. On the west coast of Africa (the "Gold Coast"), auriferous conglomerates described as strongly resembling those of the Witwatersrand are also found; and in some places the gold tenor seems to be of sufficient grade to permit profitable mining, were economic conditions more favorable.

Dikes and Faults.—These are so frequent as to affect materially the disposition of mining-plants and the exploitations upon the different properties. In estimating the tonnage of expected product, at least 15 per cent. must be deducted from the total reef-area as an allowance for faults, etc. Frequently, however, the faults are so reversed as to give a reduplication of the reefs. The Simmer and Jack fault is one of the most important. This is caused by a dike, striking E. 32° S., dipping slightly NW., and resulting in the throw of the line of reefs, on the E. side of the dike, about 1200 feet to the north.

There are also many interbedded dikes, which, however, in few instances have had any demonstrable effect on the gold-contents of the reefs. Fig. 5* shows the occurrence of a gold-bearing bedded dike in the Ferreira. Overlying this gold-bearing dike is a vein of quartz, which is distinctly auriferous. Among other instances of the proximity of a dike affecting the gold tenor of the reefs, one of the most notable is at the Bufflesdoorn mine, where the payable section of the reef is determined entirely by the proximity of the dike.

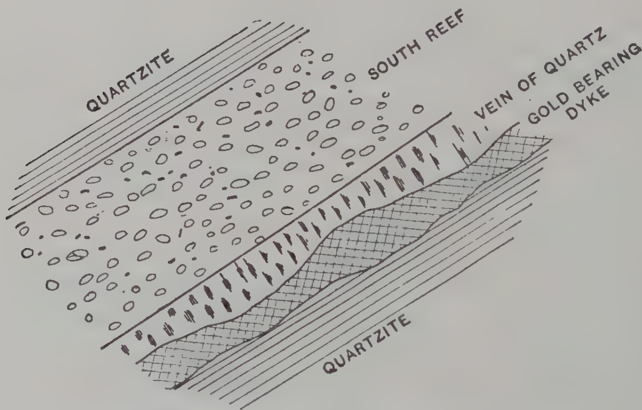
---

* From Mr. Truscott's book, p. 112.

The dikes have various strikes, sometimes more or less parallel with the strike of the reefs, and again crossing reefs almost at right-angles. Some of the many interbedded dikes may have been formed during the formation of the conglomerate-beds, but by far the greater number are intrusive. That they are of different ages is shown by the fact that they frequently fault one another. They vary in width from a few inches to about 300 ft.—rarely more than that. Petrologically these igneous "ricks" or dikes belong to the group of basic greenstones.

The gold of the banket is finely divided, and generally crystalline, though sometimes flaky and scaly, indicating a detrital

Fig. 5.



Interbedded Dike in the Ferreira Mine.

origin. Its fineness varies from about .800 to .860, from 150 to 115 thousandths being silver. Visible gold occurs sometimes, but rarely, in the matrix. Frequently the gold constitutes a thin facing or plating upon fissured planes of the quartz-pebbles. It is found also, though rarely, in the secondary silica which envelopes the quartz-pebbles, and partly fills the interstitial spaces between them.

Besides free gold, auriferous iron pyrites occurs, constituting, in the unoxidized zones, an average of about 2.5 per cent. by weight of the vein-filling. In the richer mines the pyrites carries from 4 to 6 oz. of gold per ton of concentrates. Marcasite, copper pyrites, zincblende, galena, and a few other metallic minerals, are likewise occasionally found in small quantities in

the banket. Arsenical pyrites is fortunately absent, and antimonial minerals are rare.

These reefs are called banket-reefs on account of the resemblance of the material to the confection called "almond-rock" (*Banket*, in Dutch).

V. Genesis of the Auriferous Banket.

As to the mineralization of the conglomerate beds, there is still a considerable variety of opinion.

The theory that the gold has been derived from the degradation of pre-existing quartz-veins and deposited in the conglomerate-beds (which, according to this theory, were of fluviatile origin) is untenable, inasmuch as there is no tittle of evidence in favor of the placer-character of the deposit. It is, indeed, entirely irreconcilable with all the observed conditions, and the theory is entertained by very few engineers of prominence.

The precipitation-theory is, that the sea in which the banket was deposited was a saturated solution of gold and pyrite, and that the auriferous contents were deposited *pari passu* with the accumulation of the conglomerate-beds. Concerning this subject I may quote from an article contributed by me to Mr. Truscott's book:*

> "A valid objection to the theory of precipitation is that the gold is confined to the strata of pebbles, *i.e.*, the banket, and does not occur in the interstratified sedimentary rocks, *except rarely where such rocks occur as 'horses' or inclusions in the conglomerate-bed.*"

In a recent publication† Dr. John R. Don, of New Zealand, says that all his experiments have signally failed to show any precipitation of gold from sea-water by natural agencies, and that, after most minute and extensive investigation, he finds no support for the belief that the deposition of gold and silver by such reagents in marine sediments is now going on. His careful examination of many stratified rocks, known to be consolidated marine sediments, detected in no instance the presence of gold which could be ascribed to precipitation during the period of sedimentation; and he asks the question, most

* *The Witwatersrand Gold-Fields, Banket and Mining Practice.* Macmillan & Co., London and New York, 1898, pp. 123–128.

† "Genesis of Certain Auriferous Lodes." *Trans.*, xxvii., 564 (1897).

pertinent to the present discussion, If such deposition was the rule in former periods, so that this is the origin of the gold in stratified formations, why should only a comparatively small portion of such formations be traversed by auriferous veins? According to the precipitation-theory, there must have been either an intermittency in the precipitation of gold from its menstruum, or a periodicity in the occurrence of the saturated solution of gold and pyrite in the sea, to explain the gold-tenure of the gravel-beds, and the total absence of gold in the inter-stratified sandstones and quartzites. Either hypothesis, he says (and I must agree with him), seems untenable.

In the marine theory advanced by Dr. Becker,* and supported by some important advocates, the formation of the conglomerate-beds is explained in accordance with the views of the writer; but the gold-contents of the reefs are referred to placer-origin, the presence of the crystalline gold in the banket being ascribed, however, to secondary action. According to this theory, the bulk of the gold should invariably occur on the foot-wall (or in the lowest portions, at least) of the reefs, as the result of the concentration to which the pebbles and the accompanying gold, composing the conglomerate-beds, was subjected, under the action of tidal-waves during the period of deposition. It is true that the larger pebbles generally occur near the foot-wall of the reef, and also that the bulk of the gold is usually found with the coarser pebbles; but there are important exceptions to this distribution of the gold. In some reefs—and indeed in some portions of the same reef—it is found in the hanging-wall portion of the reef, even where the pebbles composing that portion are smaller than those upon the foot-wall. There are also many instances in which the gold tenor is chiefly confined to the central portion of the reef, irrespective of the size of the pebbles, the foot- and hanging-wall portions being relatively poor in gold. Under this theory, how can we explain the fact that the large body of conglomerate constituting the main reef carries so little gold as to be non-"payable," while immediately above it, and separated from it at different places by a thin band of quartzite or schist, is the rich Main Reef Leader? And how can we explain the persistency of the gold tenor in

* *U. S. Geol. Sur.*, 18*th Ann. Rep.* (1896–7), part v., p. 153.

the small reefs, as contrasted with the poorness of other parallel reefs separated from them by but a few feet of schists or quartzite? Many of the large-pebble conglomerate-beds near and parallel to the Main Reef contain but traces of gold. Indeed, in the Main Reef series itself, the South reef, which contains the smallest pebbles of all the associated bankets, is almost invariably the richest. There is no doubt that, to a great extent, these reefs have derived their quartz-pebbles from the *débris* of the same pre-existing quartz-rocks; but it is impossible to conceive why one of the reefs should be rich in gold for many miles along its strike, and for several thousand feet in the direction of its dip, while another reef in close neighborhood should be comparatively barren.

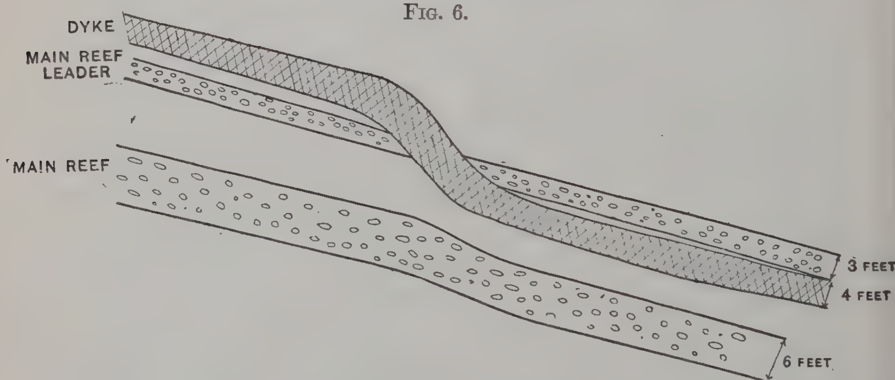
There are several other facts which militate against this theory, one of the most important being the occurrence of well-defined pay-shoots in the reefs. The advocates of the marine theory admit the force of this objection to its validity, and explain the mineralization of these ore-shoots by an auxiliary impregnation theory, to which I shall presently refer. Well-defined pay-shoots are, however, rare. The pay-ore occurs in patches rather than in defined shoots. The elongated patches characteristic of the pay-ore bodies of the Rand frequently partake roughly of the shape of ore-shoots; but, on the other hand, shoots of pay-ore in quartz-veins quite as frequently assume shapes identical with these so-called pay-ore bodies of the Rand. The line of demarkation is at times obscure.

The impregnation-theory to which I have referred commends itself most favorably to the resident mining engineers of the district. This theory attributes the presence of gold and pyrite in the reef to deposition from infiltrating solutions, as in the genesis of auriferous quartz-veins. According to this view, the mineralizing solutions have come up along the planes of least resistance, *i.e.*, the interstitial spaces of the banket of the reefs; and the gold, therefore, was deposited after the upheaval of the conglomerate-beds. While, as a general thing, the dikes traversing the conglomerate-beds have no recognizable influence in the enrichment or impoverishment of the auriferous reefs, there are important exceptions, to some instances of which I have previously alluded. A very instructive illustration of the enrichment of reefs, due to the proximity of dikes,

is furnished by the Worcester mine, a sketch of which is given in Fig. 6.* Here is an intrusive dike which, in the upper levels, lies immediately above the Main Reef Leader. In these levels the hanging-wall portion of the reef is very much richer than the foot-wall portion. This character is maintained until the lower levels are reached, when the dike, having crossed the banket, forms its foot-wall. From this point the bulk of the gold-contents of the reef is found on the foot-wall.

It is not unusual to find many quartz-pebbles cracked as the result of the movement connected with the upheaval of the formation. These pebbles have been subsequently re-cemented by infiltrating quartz solutions, and in the re-cemented cracks

FIG. 6.



Interbedded and Locally Intersecting Dike in the Worcester Mine.

are frequently found lamellæ of gold. Sometimes the quartz-pebbles are encrusted with minute crystals of quartz, which must have been deposited from infiltrating siliceous solutions after the upheaval of the beds. Combs and geodes, similar to those found in quartz-veins, occur in the banket of the reefs, which, moreover, is frequently underlain or overlain by quartz-veins carrying gold. Again, when tests of the fineness (*i.e.*, purity) of the gold have been made, it has been found that the banket and the accompanying quartz-reefs closely agree in this respect. While not conclusive proof, it is, in my judgment, more than a coincidence, that the fineness of the gold in the banket of the reef (especially in view of its minutely divided

* Mr. Truscott's book, p. 111.

condition) is comparatively low. Placer-gold under similar conditions would be usually of higher fineness.

It is thus indicated that the reefs were mineralized mainly by ascending solutions. The occurrence of considerable amounts of gold, in water-worn particles, and hence of detrital origin, is the natural result of the derivation of the quartz-pebbles of the banket from pre-existing quartz-reefs.

VI. Mining Plants and Methods.

The methods of mining in the Witwatersrand district present no features specially different from those followed in the exploitation of similar deposits elsewhere. Fortunately the ground stands well, and little timbering is required—a most important consideration in a country where mining-timber is so scarce. The mines are what mining engineers would call "dry"; the water being usually seepage, and varying from 50,000 gal. per day, for a shaft sunk upon the outcrop of the reefs, to less than 5000 gal. for a shaft sunk upon the second row of deep levels, where the reefs are reached at a vertical depth of about 2000 ft. This statement represents fairly the average quantity pumped in the district under the conditions described; but in some places, in sinking shafts, even upon the first row of deep levels, we have encountered an influx of water as great as 50,000 gal. per hour. These rare cases were in broken country, where the watershed conduced to a copious supply.

The amount of water available for boilers, batteries, cyanide-treatment, etc., is, even in the present state of development of the industry, inadequate, and presents a difficult problem to the mine operators. The water from the mines is usually acid, and hence not desirable for boilers. The necessary supply of water is at present made up by local storage of rain-water. The average rainfall in the vicinity of Johannesburg is from 25 to 30 in. per annum; but, being more or less torrential in character, and limited to a few months, it is somewhat difficult to impound. There are, however, within 20 or 25 miles of Johannesburg, other sources of water-supply, which will probably be utilized in the future.

Cornish pumps are by far the most common type of pumping-machinery, though electric pumps are coming into use, especially in shaft-sinking, where the water to be handled is unknown and variable in quantity.

Air-drills are extensively used upon the Rand, especially for development-work, which is energetically carried on. The Ingersoll-Sergeant, Reidler, Allis and Walker drills are the most popular. Electric drills have been tried, but thus far without success.

The boilers used are of nearly all types. The water-tube boilers of Babcock & Wilcox and Heine, and the horizontal multitubular boilers are most extensively used. The earlier installations included the Lancashire, the Cornish, locomotive-boilers, etc.

Mining Plans.—Great attention is given to the preparation of maps of the underground workings, geological sections, and plans upon which assays are plotted. In these respects the Rand practice is far ahead of that of any other country with which I am familiar.

Hoisting.—Hoisting is done by cages and self-dumping skips. The head-gears have in the past been chiefly constructed of wood; but the use of steel head-gears is now becoming more general, especially in the deeper mines.

VII. Milling.

Before going to the battery the ore is sorted, either in a central sorting-station, or more commonly in a sorting-house immediately adjoining the head-gear. The ore is tipped upon a grizzly, the fines passing through to the ore-bins. No attempt is made to assort the fines. The coarse material is usually sorted on a revolving table or a moving belt, water being sprinkled on the stuff before it reaches the sorters, who are Kaffirs, directed by white bosses.

From 10 to 40 per cent. of the waste is eliminated by sorting, at an average cost of 6 pence per ton sorted. The sorted ore is then crushed in machines, either of the gyrating class, of which the Gates crusher is a type, or of the reciprocating class, of which the Blake is a type. In some cases, a second sorting follows crushing. Out of 8,979,328 tons of ore mined in 1898, 7,331,446 tons were milled. The difference, 1,647,-882 tons, being 18.35 per cent. of the total amount of ore mined, was waste, sorted out at the surface.

The mills are usually situated close to the shafts, and the ore is elevated by different devices into the ore-bins. The stamp-

batteries are of the usual type of gold-mills, recently installed. Mills of less than 60 stamps are rare on the Rand. The tendency is towards larger plants. The usual size of recently erected mills is 200 stamps.

As already observed, the gold occurs in the cementing-material which encloses the pebbles. Fine grinding is therefore not necessary. The aim among the mill-men of the Rand is to utilize the greatest crushing-capacity of the battery, and not to depend to any great extent on battery-amalgamation; the expectation being that the free gold, which is readily amalgable, will be caught on the outside plates. In many cases, therefore, inside battery-amalgamation is not practiced. The meshes of the screens range between 500 and 900 per sq. in. The amount of water used in crushing is about 8 tons per ton of ore crushed. Of this water about 75 per cent. is saved by settling, and used over again for the battery; the loss due to leakage, evaporation and absorption by the tailings being about 25 per cent.

The average capacity per stamp per day for the district is 4.68 tons. This capacity is gradually being increased by the use of heavier stamps, coarser crushing, etc. In some of the recently erected batteries, nearly six tons of ore per day is the duty per stamp.

In the larger mills, the batteries are placed back to back.

The cost of a 200-stamp mill, to crush 1000 tons per day, is:

200-stamp mill, "back to back,"	£49,000
45-ft. double tailing-wheel,	2,250
750 H.-P. mill-engine and condenser,	6,800
1000 H.-P. boiler-plant,	15,000
Engine and boiler-houses,	3,000
Plant for hauling ore to mill,	2,000
Water-service and reservoirs,	25,000
Total,	£103,050

By amalgamation on copper plates, about 65 per cent. of the total gold-recovery is effected. There is no arsenic, antimony or zinc in the ore, and the quicksilver-loss is small,—not over 2 lbs. per stamp per month. In but few of the mills are concentrators employed. They are chiefly used along the eastern portion of the central section, where the pyrites does not seem to yield readily to cyanide-treatment. In some of these mines from 10 to 12 per cent. of the total gold-contents

of the ore is obtained from the concentrates, which assay from 4 to 5 oz. per ton, and represent 2.5 per cent. in weight of the ore treated. The cost of concentration is about 9 pence per ton of ore. The concentrates are treated by chlorination at a cost of from £2 to £2 10*s*. per ton, with a saving of 98 to 99 per cent. of the assay-value. The total amount of fine gold obtained from the concentrates for the mines in the district for the year 1898 was 139,427 oz., having a value of £489,097.

VIII. Treatment by the Cyanide Process.*

The following description applies to the treatment of ores in the pyritic zones. Ores from the upper (oxidized) horizons of the reefs, which constitute but a small percentage of the ores treated, require a slight modification of the process.

The ground near the mines is level, and does not permit transportation by gravity. Consequently, the ore must be first elevated into the ore-bins at the mill, and the tailings leaving the mill must be elevated for treatment by the cyanide process. This is done either by tailing-pumps, or, preferably, by tailing-wheels. These are from 40 to 50 ft. in diameter, and discharge the tailings into a launder, which, with a grade of about 3.5 per cent., carries them to the cyanide-works. The auriferous pyrites is to a large extent taken out as concentrates by means of *Spitzlutten* (hydraulic classifier). About 10 per cent. of the mill-pulp recovered in this way consists of pyrites with coarse sand, a concentration of 10 to 1 being obtained. These concentrates are taken to tanks for separate treatment. From two to three weeks of treatment is required in order to obtain from this material a recovery of from 90 to 95 per cent. of the gold it contains. A solution of about 0.25 to 0.3 per cent. of cyanide of potassium is used. After passing over the *Spitzlutten* the tailings are run to *Spitzkasten* (pointed boxes), where the heavier sands are allowed to settle, while the lighter material (slimes) overflows and is carried to the slime-works for special treatment. The sands which settle in the *Spitzkasten*, representing about 70

---

* Experiments have been made on a large scale for the treatment of the ore by dry crushing and cyaniding. The results of these tests are embodied in the *Transactions of the Institution of Mining and Metallurgy*, London, for 1899. This process has as yet not secured the approval of the mining engineers of the Rand, and is used in a small way only by one or two of the less important companies.

per cent. of the battery-pulp, are continuously discharged by pipes leading from the bottom of the box, and are delivered by a hose or by an automatic revolving distributor to settling-tanks, into which they are so fed as to be as thoroughly mixed as possible. This separation of the sands from the slimes has to be carefully made, so as to remove all clayey substances, the presence of which would otherwise prevent rapid percolation of the solution and the free access of atmospheric oxygen, which is essential to the solution of gold by cyanide.

Most of the modern plants have a system of double treatment, the tailings being settled in the settling-tanks, when they are treated, after being allowed to drain, with a weak solution of cyanide of potassium. This addition of the cyanide of potassium is made rather for the purpose of *saturating the sands with the solution* and subsequent aëration than for thorough leaching, which would be difficult, on account of the packing of the sands as they are settled, rendering percolation difficult; the aëration is obtained by the discharge (usually by shoveling) from the upper to the lower tank, thereby securing a more rapid and complete solution of the gold in the later treatment. After the solution has been drained off, the sands from the settling-tanks are discharged into the leaching-tanks, placed immediately below the settling-tanks, from which they are filled from discharge-doors on the bottom of the latter. For a 200-stamp plant, 16 steel settling- and 16 steel leaching-tanks are usually employed. From 3 to 4 settling- and leaching-tanks are used for the treatment of the *Spitzlutten* concentrates above described. The settling-tanks are usually 40 ft. in diameter and 9 ft. high. The leaching-tanks have the same diameter, but usually a foot less height. The capacity of these tanks is about 400 tons of pulp each.

In the leaching-tanks the pulp is subjected to three treatments with cyanide of potassium. Where the McArthur-Forrest process is used the strong solution contains 0.25 per cent.; the medium solution 0.2 per cent., and the weak solution, 0.10 per cent. of KCy. In the Siemens-Halske process the solutions are weaker, namely, the strong solution, 0.10; medium, 0.02, and weak, 0.01 per cent. of KCy.

The treatment requires from 4 to 7 days. From 130 to 150 tons of solution are usually employed for 100 tons of sand.

After being allowed to drain, the sands are discharged through bottom discharge-doors into trucks, in which they are removed to residues or tailings-heaps. Here, again, elevation is necessary, on account of the flatness of the country, and is usually effected by the endless-rope system. These tailings-heaps are conspicuous throughout the mining district. By reason of the heavy winds prevailing at certain seasons of the year, they are becoming a great nuisance; and the question of their future disposition is one of the problems for the mining engineer.

The cyanide-solution, after being drawn off from the leaching-tanks, is taken to the precipitation boxes. The gold from the strong solution is precipitated in one set, and that from the weak solution in another set of boxes. Precipitation is effected by either the McArthur-Forrest or the Siemens-Halske process.

The McArthur-Forrest Process.—In this process the gold is precipitated by zinc, the solution passing upwards through a succession of compartments, in which are placed zinc shavings or filings, resting on a movable tray of coarse screening. About 20 precipitation-boxes, 20 ft. by 3 ft. by 3 ft. 9 in. in size, are used. The gold-bearing solution is brought into close contact with the zinc, causing the deposition of the gold, partly as a metallic coating on the zinc, and partly as gold slimes, which sink to the bottom of the box. As the zinc is gradually dissolved by cyanide, more is added.

Once or twice a month the boxes are emptied, and the gold-slimes are treated with dilute sulphuric acid, then dried and melted in crucibles. The dried slimes contain about 15 to 20 per cent. of gold, and after fluxing with borax and soda, an ingot of .750 to .800 fineness in gold and .100 in silver is obtained. The slag, carrying from 5 to 50 oz. gold per ton, is usually sold to smelters.

This precipitation process yields satisfactory results only with solutions containing more than 0.1 per cent. of cyanide, the weaker solutions not being acted upon by zinc. An improvement of the method is the addition of lead to the zinc, whereby the combination of the two metals forms a galvanic couple, which also reacts with weaker solutions, such as are employed, for example, in the treatment of slimes.

The Siemens-Halske Process.—In this process the solution

flows through compartments very similar to the zinc-boxes above described, but the zinc shavings are here replaced with lead strips (0.1 lb. per sq. ft.) or shavings hung between iron plates placed vertically and longitudinally in the box, about 4 in. apart. The lead strips are connected with the negative, and the iron plates with the positive, pole of a dynamo; and the solution is thus electrolytically decomposed, the gold being plated on the lead cathode. The iron plates are wrapped in canvas to prevent short-circuiting. The current employed is from 2 to 3 volts, giving a current-density of about 0.06 ampères per sq. ft. of cathode. Once a month the lead sheets are removed and replaced, and the gold-coated lead is melted and cupelled, yielding a bullion of .880 fine in gold and .100 in silver. The litharge is sold to smelters. The solutions passing through the treatment-boxes are collected in tanks, and are made up to a proper strength by adding the necessary KCy.

The cost of the Siemens-Halske process is slightly greater than that of zinc precipitation, and the percentage of extraction is about the same. But the Siemens-Halske process may be applied to any solution, weak or strong.

IX. The Future of the Witwatersrand Gold-Fields.

During the eight months ending in August, 1899, after which the commencement of active hostilities interfered with the active working of the mines, the Witwatersrand produced £12,485,032 sterling. At this rate, the year's production would have been £18,727,548. As a matter of fact, it would have amounted to some 20 millions sterling, by reason of the progressive increase in the monthly production already shown during that year. Of this output 71 per cent. was derived from what is known as the central section, extending about 1.5 miles W. and about 8 miles E. of Johannesburg; and 24 per cent. was derived from the deep-level properties within that section. The total gold-product of the Witwatersrand was 25.5 per cent. of that of the entire world. Notwithstanding the increased production of gold elsewhere, this ratio would have been more than maintained had mining operations not been interfered with by the South African war. Within one year after the resumption of mining operations, upon the scale existing immediately prior to the war, an output of gold at the rate of

over 20 millions sterling annually may be reasonably estimated; and this rate of production will be steadily increased, partly by the increase in the crushing-plants of some of the companies, but more especially by the starting of many of the deep-level properties which will then reach the producing stage. Within the next three or four years, after operations have been resumed on a large scale, the annual gold-production from the Witwatersrand may reach 25 millions sterling. Beyond this amount there should be a further increase, the amount of which it is impossible to estimate. In from 6 to 8 years some of the important gold-producers among the outcrop-companies will fall out of line, by reason of the exhaustion of their mining areas. To what extent this deficit will be counterbalanced by increased yield in the deeper-level properties cannot be as yet determined. Much depends upon the policy adopted by the larger companies owning these properties.

In the reliability of its ore-bearing formation, the Rand is unique in the history of gold-mining; but in the minds of many an exaggerated importance is attached to the persistency of payable ore-bodies in strike and in dip. There is indeed considerable fluctuation in the value of the ore within the same reef, even within short distances; but a remarkably even grade of ore has been maintained since the inception of the industry. Where there has been an apparent falling off in yield per ton during any year, the fact is to be attributed rather to the working of lower grade ores, made possible by improved economic conditions, than to a depreciation in the ore-values of the reefs themselves.

The results of the developments in the deep-level areas have been so satisfactory as to engender a certain recklessness on the part of mining companies owning very deep reefs. The exploitation of certain of these areas is not regarded by conservative engineers as at present justified, in view of the large intervening tracts of undetermined value which separate mines in operation from the site of proposed mining upon these very deep-level areas. To what extent mining can be carried on in depth in the Transvaal is a most interesting and important problem. The conditions there are certainly most favorable for mining at great depth. From present indications the influx of

excessive quantities of water is not to be apprehended. In respect to temperature, the district is especially fortunate, in that the increment of temperature with depth thus far observed has been abnormally low. In the case of the Robinson Deep mine, it is about 1° F. for 212 feet of vertical depth. With the exception of the additional costs of haulage, pumping and ventilation, there are no factors operating against mining on the Witwatersrand to a depth of at least 8000 feet vertically. These costs will not afford any insuperable obstacle to profitable mining, provided, of course, the geological character of the deposit is not adversely changed. So reliable is the formation, from a geological point of view, as regards its mining potentialities, that engineers have felt justified in assuming the existence of payable ore at depths of 1000 feet vertically and upwards beyond the extent in depth of any mining operations. Thus far the results of actual operations upon these areas have justified their position. It is estimated that for every mile in length along the course of the reefs, down to a vertical depth of 1000 feet for the dip of these reefs, gold to the value of about £10,000,000 will be extracted. This is a conservative estimate —at least as applied to the central section of the Rand. If we assume these conditions to obtain to a depth of 6000 feet vertically, we have the enormous sum of £60,000,000 for each mile in length. It is not unreasonable to suppose that these conditions will be maintained along most of the central section, say for a distance of 10 miles, in which case we would have an auriferous area, within practicable mining depths, containing upwards of £600,000,000 value of gold.

It is less safe to make any prediction of the gold-product to be expected from the E. and W. sections; but it is perfectly safe to say that the output of these sections would very greatly augment the amount I have named. Messrs. Hatch and Chalmers, well-known engineers of extensive South African experience, compute the available gold from these portions of the Rand at £200,000,000.

It is impossible to predict with any accuracy the duration of mining in the Witwatersrand district, by reason, especially, of the indeterminate factor of the rate at which exploitation will be carried on. It may be observed, however, that the tendency is to exploit the auriferous areas as rapidly as possible, and that

engineering methods are all adopted with that end in view. If the exploitation of the deeper levels is not delayed pending the proving of the ground lying above, but is carried on concurrently with the exploitation of the higher horizons of the reefs, the industrial life of the district will, of course, be correspondingly shortened. The working of lower-grade ores, made possible by improved economic conditions or other circumstances, would tend to increased longevity of the industry. But, were I called upon to express an opinion, I would estimate the future duration of profitable operations on a large scale in the district at less, rather than more, than 25 years.

The future looks from all points of view encouraging. We may reasonably anticipate important improvements in economic conditions as the result of the establishment of a better government. I believe that, as the result of economic reforms, there will be an ultimate saving of 6s. per ton of ore treated, as compared with the conditions under which mining has been carried on under the government of the late South African Republic. This refers to all savings, both direct and indirect, and especially the economy resulting from increased efficiency of labor due to the betterment of living conditions. Positions formerly commanding a salary of $15,000 a year will be satisfactorily filled for $10,000. For the tonnage of ore crushed in 1898, this would result in an increase of annual dividends of £2,199,405.

Postscript.

The acute and courteous criticism of my friend Mr. Thomas H. Leggett,* in his discussion of the first pamphlet edition of this paper, affected the statistics therein given and the views therein expressed. The latter I have not modified in my revision, except by making them, here and there, more explicit and clear, and guarding them from misconception. The former have been considerably changed; the result sometimes agreeing, and sometimes disagreeing, with the corrections made by Mr. Leggett. The fact is, that, although my revision of them has been made independently of his figures,—*i.e.*, I have not used his statements as my authority,—nevertheless I have had the advantage of seeing his criticisms, and

* Secretary's Note.—Mr. Leggett's contribution will be found in the last part of this volume, under the head of Discussions.—R. W. R.

am grateful to him for calling attention to many discrepancies and inaccuracies, which, in my own careful re-examination, I might, indeed, have detected, but which, after receiving this aid from him, I could not possibly overlook. It may be added that the discrepancies between statistical statements in my first edition, or between any of those statements and the figures given by Mr. Leggett, or those contained in these pages, are not great enough to affect general conclusions. Nevertheless, I heartily recognize, even in matters not permitting perfect accuracy, the professional duty of being as accurate as possible; and I think every technical author ought to feel, as I certainly do, that a correction of facts or figures is not a hostile judgment, but a friendly service.

Slag-Constitution, Studied by Means of the Tri-Axial Diagram with Rectangular Co-ordinates.

A Discussion, Suggested by Prof. H. M. Howe's Paper, "The Tri-Axial Diagram" (*Trans.*, xxviii., 346), and Prof. H. O. Hofman's Paper, "The Temperatures at which Certain Ferrous and Calcic Silicates are Formed in Fusion" (*Trans.*, xxix., 682).

BY HARRISON EVERETT ASHLEY, S.B., NEW BEDFORD, MASS.

(Mexican Meeting, November, 1901.)

The Tri-Axial Diagram.

Lime-Ferrous Oxide-Silica.

Prof. Hofman's diagrams, Figs. 5 and 7 of his paper, which are reproduced as Figs. 1 and 2 of the present contribution, confessedly fail to show comprehensively the properties of the silicates investigated. Each curve is carefully discussed, and the author has evidently drawn all the conclusions that can be thus reached; but he says:*

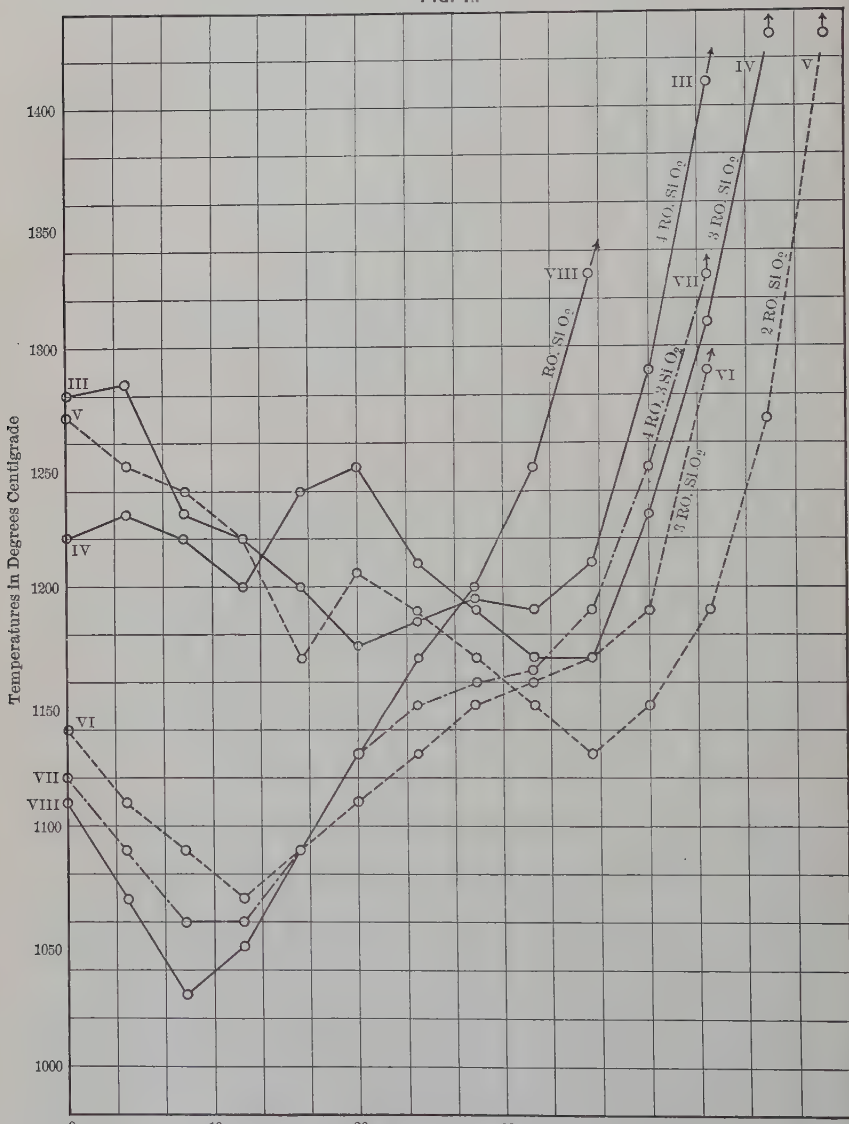
"The curves do not show, as was hoped, any simple connection between silicate-degree, percentage of lime, and minimum of formation-temperature."

There is, therefore, in this case, an excellent opportunity of

* *Trans.*, xxix., 708.

testing the tri-axial diagram as a means of throwing more light on the interpretation of these data.

FIG. I.



THE FORMATION OF FERRO-CALCIC SILICATES

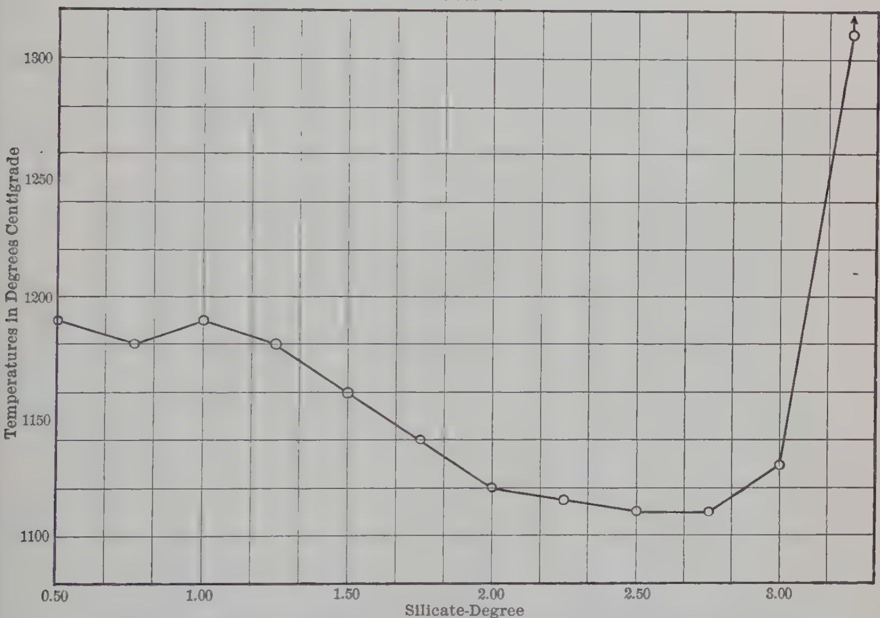
(Being Fig. 5 of Prof. Hofman's Paper, *Trans.*, xxix., 699.)

This means has been used for representing graphically the physical properties of ternary alloys—freezing-points, limits of

perfect miscibility, tensile strength, elastic limit, contraction of area at fracture, etc. Prof. Howe has pointed out its application in exhibiting the properties of slags. Prof. Hofman's results are thus plotted in Fig. 3.

The tri-axial diagram is applicable only to the case of *three variables whose sum is a constant*, that is, to two independent variables. For example, if an alloy of tin, copper, and zinc be assumed to contain 15 per cent. of tin and 80 of copper, the percentage of zinc must be 5, the difference between

FIG. 2.

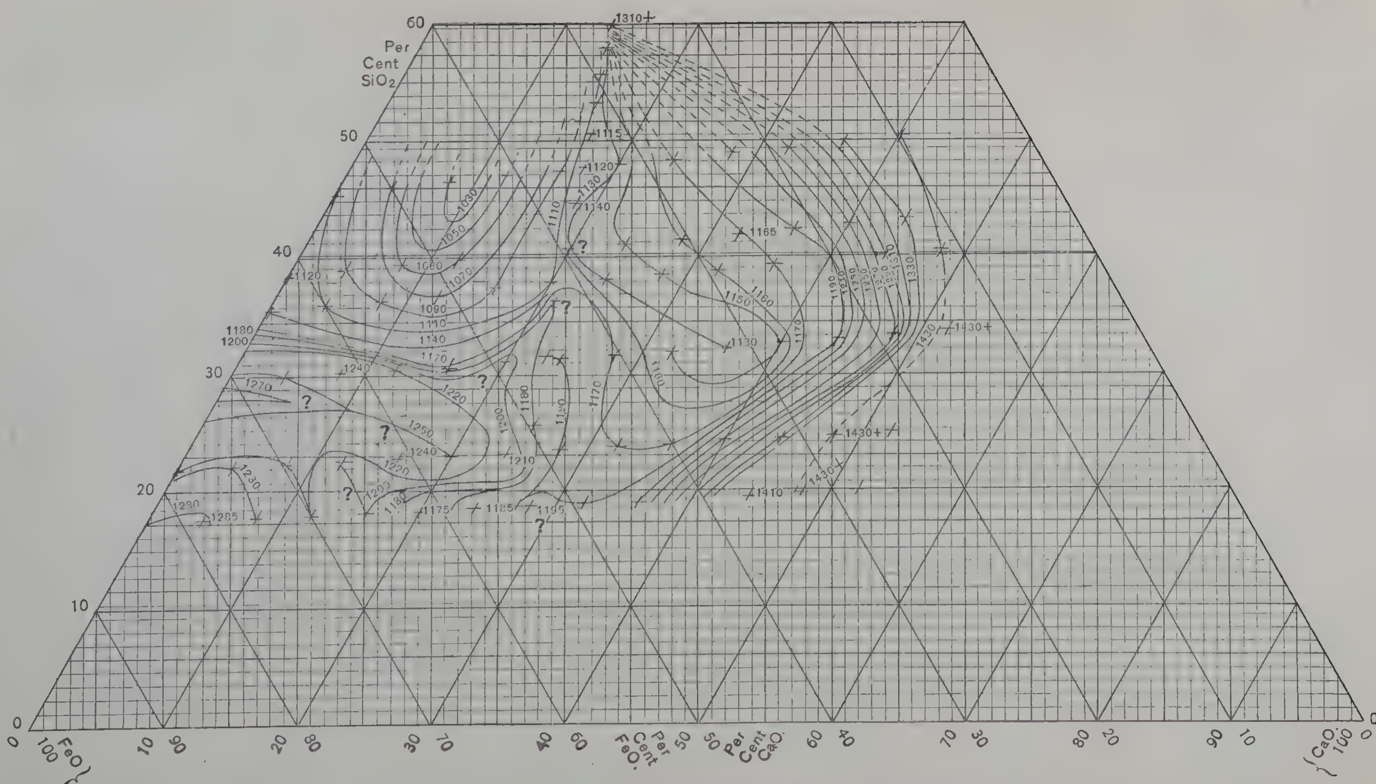


CROSS-SERIES, SHOWING EFFECT OF INCREASE OF SILICA UPON FORMATION-TEMPERATURE.
(Being Fig. 7 of Prof. Hofman's Paper, *Trans.* xxix., 701.)

15 + 80 and 100. When the percentages of tin and copper have been fixed, that of zinc cannot be varied. But two independent variables can be shown by the common diagram with rectangular co-ordinates. A diagram showing only tin- and copper-percentages will serve to illustrate all the properties of the ternary bronze. Why use, then, the inconvenient oblique equilateral-triangle diagram, when results can be plotted with comparative ease on ordinary cross-section paper, with rectangular co-ordinates, in an erect, right-angled triangle?

Moreover, it is possible to read off from such a plot the third or

Fig. 3.

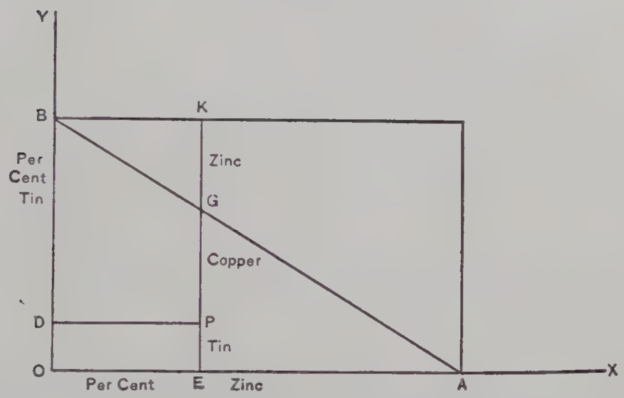


Formation-Temperature of Ferrous Oxide-Lime-Silica Slags. (Plotted from Prof. Hofman's Paper, *Trans.*, xxix., 682.)

Note.—The numbers in the diagram indicate degrees Centigrade.

dependent variable. In Fig. 4, let any vertical line (as EK = OB) represent 100 per cent. of whatever mixture is under consideration, say tin-copper-zinc. Further, let the lower part (EP) of

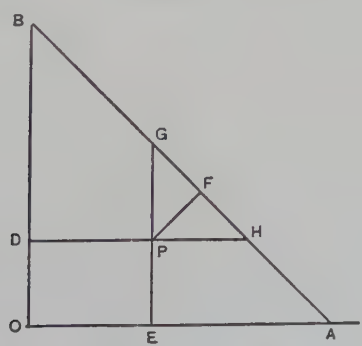
FIG. 4.



Diagram, showing Method of Plotting Three Variables with Rectangular Co-ordinates.

the line represent per cent. of tin; the upper part (GK) represent per cent. of zinc, and the middle part (PG) per cent. of copper. Then arrange the vertical lines along OX so that the ab-

FIG. 5.



Diagram, showing all Three Variables Measured by the same Scale (Isosceles Right-Angled Triangle).

scissæ also shall represent the percentage of zinc (*i.e.*, OE = percentage of zinc). We have now the per cent. of zinc represented by two separate means, one of which is superfluous; and we

may accordingly dispense with the upper part of each vertical line, reducing the diagram from a rectangle to the triangle AOB. For any point P, the abscissa DP (= OE) represents per cent. of zinc; the ordinate PE (= OD) represents per cent. of tin; and the distance along the vertical line PG to the hypothenuse AB, per cent. of copper. The scales for the two quantities measured along the vertical lines are from the nature of the case the same, while the scale for the quantity measured by the abscissæ is the same as for the other two only in the case of the isosceles right-angled triangle. It is desirable to have all three variables plotted to the same scale. It may be noted that in the case of the isosceles right triangle, Fig. 5,

$$\begin{aligned} PG = PH = \sqrt{2} \times PF = BD - PD = EA - PE \\ = OB - PD - PE = OA - PD - PE. \end{aligned}$$

It is evident that the same principles may be applied to plotting data of the forms $a + b - c = k$ and $a - b - c = k$, or, in general, of the form $ma + nb + pc = k$, where m, n, and p are any positive or negative, integral or decimal, real co-efficients.

Making use of the preceding principles, Professor Hofman's results are replotted in Fig. 6 on ordinary plotting-paper. His work shows the temperatures at which the constituents of certain ferrous calcium silicate slags fuse together, *i.e.*, the formation-temperatures of those slags. The mixtures were chosen so as to correspond to silicates of certain general chemical formulæ, with iron and calcium gradually replacing each other.

Percentages of silica are represented by the ordinates, percentages of lime by the abscissæ, and percentages of ferrous oxide in any one of seven ways, as indicated below. For example, the "basal slag" of the latter part of the investigation is shown at C (Fig. 6), where the ordinate CE (= OD) corresponds to 32.10 per cent. SiO_2; the abscissa DC (= OE) to 32.00 per cent. CaO; and either leg minus these two co-ordinates (AO — CD — CE or BO — CD — CE), to 35.90 per cent. FeO. The per cent. of FeO is also indicated by $\sqrt{2} \times$ the perpendicular CF to the hypothenuse; by the vertical distance CG; by the horizontal distance CH; by AE — CE; and by BD — CD. The best general way of reading the per cent. of FeO is to take the distance CG with dividers, and measure

it on the scale of the diagram. As most of the percentages of CaO in this investigation were integral, the points fall on the verticals of the plotting-paper; and the reading of FeO is thereby made so easy that it can be done by the eye alone in the following manner: Draw diagonals corresponding to each 10 per cent. of FeO. Now, in reading down the ordinate of C, U corresponds to 10 per cent. FeO; V to 20 per cent.; W to 30 per cent.; and X to 40 per cent. Between W and X are ten subdivisions, each corresponding to 1 per cent. There are between W and C five of these, equal to 5 per cent., and a part of another, which by eye-estimation is 0.9 per cent. Therefore, the percentage of FeO is $30 + 5 + 0.9 = 35.9$ per cent. Having located the different slags experimented upon, isotherms are drawn connecting those which form at the same temperature. As the same principles apply in the main to Fig. 3, no explanation is given for that plot. The data are in such form that it is most convenient to make nearly all the isotherms 20° C. apart, except in the lower left-hand corner. In certain regions the data are insufficient to give complete assurance in drawing the isotherms, and differences appear between Figs. 3 and 6, the more probable lines being given in Fig 6. Interrogation-points and dotted lines are also employed in the doubtful regions. But, on the whole, there is a very clear and valuable outlook. The almost complete absence of inconsistency shows on the one hand a surprising precision of the Seger cones, and on the other hand excellent experimental work.

The diagram, Fig. 6, shows in a simple manner the "connection between silicate-degree, percentage of lime and minimum of formation-temperature." There is a maximum, L, at 1270° C., corresponding to the pure ferrous silicate $(FeO)_2,SiO_2$ [FeO, 70.42; SiO_2, 29.58]. There is a second maximum, K, at 1250° C., corresponding to the compound $CaO,(FeO)_2,SiO_2$ [CaO, 21.55; FeO, 55.24; SiO_2, 23.21]. Midway between these points is a minimum region, M, below 1200° C. It contains over 60 per cent. FeO. A second minimum region, S, at 1030° C., contains at least 45 per cent. SiO_2 and about 10 per cent. CaO. A third minimum region, N, at 1130° C., is in the neighborhood of CaO, 35; SiO_2, 33; FeO, 32. It is somewhat like a level place on a hillside, rather than a

valley, like the first and probably the second minimum. A possible fourth minimum region, R, is indicated at 1175° C., with the composition CaO, 20.00; SiO_2, 18.19; FeO, 61.81. With high percentages of lime and low percentages of ferrous oxide, the formation-temperatures rise rapidly. The base of the rise, 1190° C., is a broken line through the following three points, the second of which is the vertex of the angle, viz.:

CaO, 32; SiO_2, 19; FeO, 49.
CaO, 44; SiO_2, 33; FeO, 23.
CaO, 27; SiO_2, 49; FeO, 24.

With 10 per cent. increase in the lime, the formation-temperatures rise very regularly to 1430° C., which is as high as the investigation went. A much higher temperature is probably attained beyond; for Le Chatelier and Boudouard consider 1700° C. as about the melting-point for CaO, 48.15; SiO_2, 51.85; and melting-points are probably slightly under formation-temperatures. High and low regions having been mentioned, it remains to be said that the intervening slopes are, for the most part, gradual. With about 32 per cent. SiO_2, and from 0 to 20 per cent. CaO, there is a sharp fall of 100° with increased SiO_2. The low formation-temperature, 1170° C., of the slag CaO, 16.00; SiO_2, 30.76, puzzled the experimenter; and the diagram shows his repeated determinations to have been very desirable in fixing a part of the steep slope. One discrepancy, however, escaped him; he found for the sesqui-silicate CaO, 20.00; SiO_2, 40.66, the formation-point 1130° C., and for the cross-series CaO, 19.74; SiO_2, 40.80, he found 1160° C.

In the freezing-point curves of binary metallic alloys or salt solutions, it is found that a maximum corresponds to the existence of a definite chemical compound at that point and temperature, while a minimum (called a "eutectic") has no such significance. This principle may be extended to ternary mixtures.* Now, slag formation-temperatures are believed to differ but little from freezing- (or melting-) points. It seems not too great a stretch of imagination to think that a maximum of

* "Solid Solutions of Mixtures of Three Substances." G. Bruni, *Atti R. Accad. dei Lincei*, Rome, ix., [5], 232–241; Chem. Centralbl. (1900) ii., [23], 1173; *Jour. Soc. Chem. Ind.* (1901), xx., [2], 160.

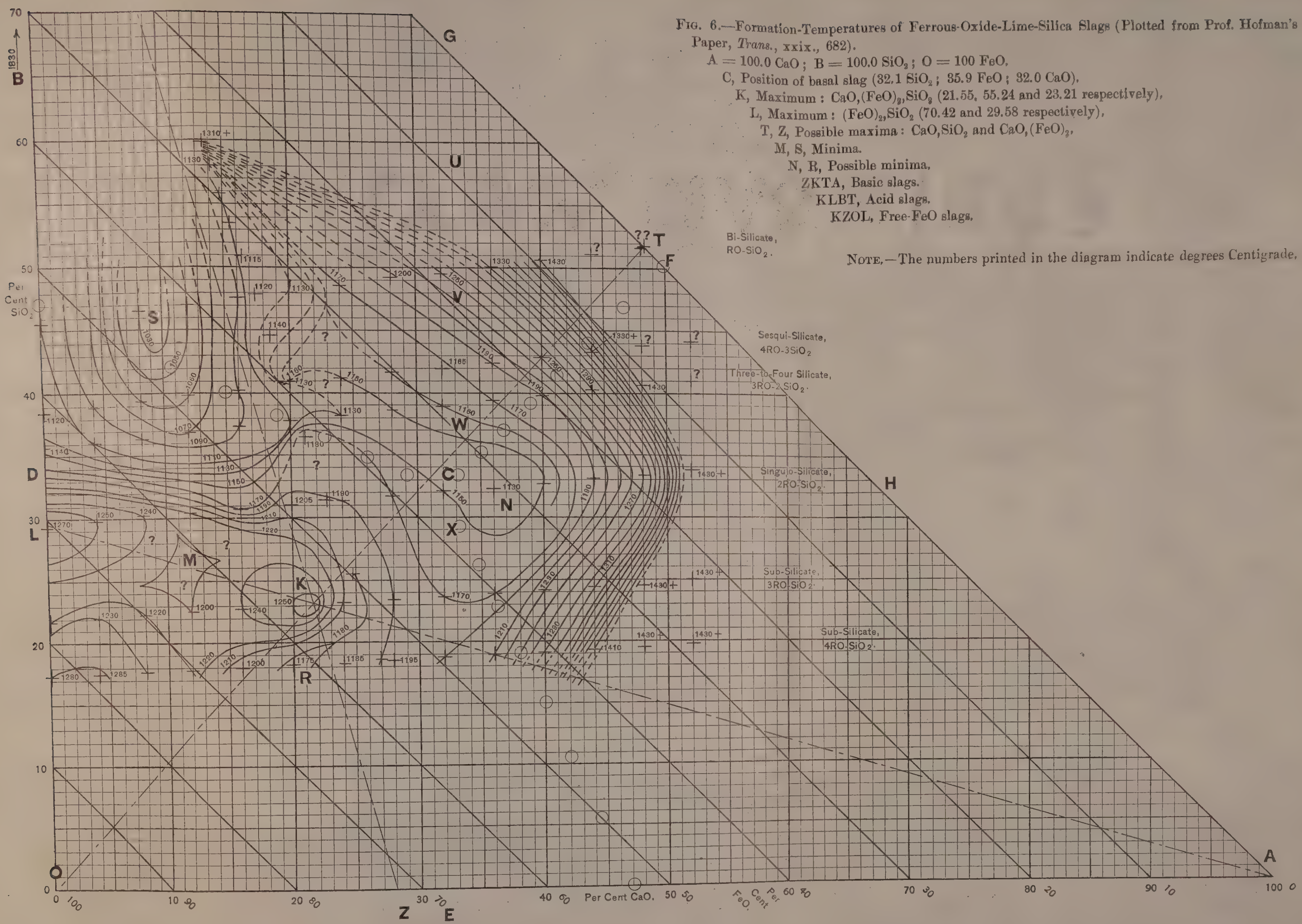


Fig. 6.—Formation-Temperatures of Ferrous-Oxide-Lime-Silica Slags (Plotted from Prof. Hofman's Paper, *Trans.*, xxix., 682).

A = 100.0 CaO; B = 100.0 SiO_2; O = 100 FeO.

C, Position of basal slag (32.1 SiO_2; 35.9 FeO; 32.0 CaO).

K, Maximum: CaO,$(FeO)_2$,SiO_2 (21.55, 55.24 and 23.21 respectively).

L, Maximum: $(FeO)_2$,SiO_2 (70.42 and 29.58 respectively).

T, Z, Possible maxima: CaO,SiO_2 and CaO,$(FeO)_2$.

M, S, Minima.

N, R, Possible minima.

ZKTA, Basic slags.

KLBT, Acid slags.

KZOL, Free-FeO slags.

Note.—The numbers printed in the diagram indicate degrees Centigrade.

formation-temperature in slag-mixtures, corresponds to the existence of a definite chemical compound at that point and temperature, and that all proportions not giving maxima are mechanical mixtures. This would seem to indicate that in the whole range of Prof. Hofman's work there are but two proportions giving definite chemical compounds, namely $(FeO)_2$, SiO_2, the formation-temperature (L) of which is 1270° C., and $CaO,(FeO)_2,SiO_2$, the formation-temperature (K) of which is 1250° C. It would be desirable to study how much heat is liberated or absorbed in forming these compounds; for if the amount be at all considerable, it will have an important bearing on fuel-consumption.*

If a line be drawn on the diagram, Fig. 6, through the two maxima L and K, and continued, it will pass exactly through the vertex A of the diagram, representing 100 CaO. It will further be noticed that all the isotherms intersected by it make angles with it approaching 90°. In passing along the line from L to K, we start at the maximum temperature 1270° C. at L, descend to the minimum 1200° C. at M, and rise to the second maximum 1250° C. at K. This is the law that would be followed by the freezing-point curve of two perfectly miscible, non-isomorphous metals, that are not capable of combining chemically with each other. The same law is also followed by solutions of single salts perfectly miscible,

* A more logical demonstration of the existence of definite chemical compounds is as follows: The line OB in Fig. 6 represents the variation of formation-temperature for all proportions of FeO with SiO_2. These are binary mixtures. The maximum at L (FeO, 70.42; SiO_2, 29.58) indicates the definite chemical compound $m\,(FeO)_2,SiO_2$. As the curve is incomplete at both the FeO and SiO_2 ends, we cannot say positively that there is no other intermediate maximum, nor, consequently, of what chemical compounds the compound $m\,(FeO)_2,SiO_2$ is made up. But it is very likely that maxima exist only at the ends and at L, and that $m\,(FeO)_2,SiO_2$ is made by a chemical combination of $2m$ FeO with $m\,SiO_2$—not by a combination of more complex compounds.

The line LA represents the variation of formation-temperature for all proportions of $(FeO)_2,SiO_2$ and CaO. These also are binary mixtures. The maximum at K (CaO, 21.55; FeO, 55.24; SiO_2, 23.21) indicates the definite chemical compound $CaO,(FeO)_2,SiO_2$. The line LK accordingly shows mixtures of $(FeO)_2,SiO_2$ with $CaO,(FeO)_2$, SiO_2. Between K and A we cannot say positively that there is no other maximum, but such seems likely to be the case; and accordingly KA would indicate mixtures of $CaO,(FeO)_2,SiO_2$ with CaO.

The microscope, if available, and cooling-curves will probably be of great assistance in determining the correctness of these views, even as they now are in studying the structure of metallic alloys.

non-isomorphous, and incapable of combining chemically with the solvent.* It seems reasonable to assume that $(FeO)_2,SiO_2$ and $CaO,(FeO)_2,SiO_2$ are perfectly miscible when fluid, are non-isomorphous, and are incapable of combining chemically with each other.†

Passing along the same line from K to A, we start from the maximum temperature 1250° C., descend to a minimum 1180° C., then rise to 1430° C., beyond which temperature the investigation was not carried. Remembering the eminent infusibility of lime, it is likely that the temperatures would continue to increase until A is reached. It is therefore probable, but not proved, that $CaO,(FeO)_2,SiO_2$ and CaO are perfectly miscible when fluid, non-isomorphous, and incapable of combining chemically with each other.

Since the line LKA showed such significant results, a line was drawn through the vertex O and the point K, continuing until it met the side AB at the point T, corresponding to the chemical compound CaO,SiO_2. This line also is nearly perpendicular to the isotherms. Passing along it from K to T, we start at a maximum 1250° C., descend to a minimum 1130° C., ascend to 1430° C., beyond which temperature the investigation did not go. Le Chatelier and Boudouard's estimate of the melting-point of CaO,SiO_2 at 1700° C. leaves little doubt that the formation-temperatures would continue to rise beyond 1430° C. It seems pretty certain, therefore, that $CaO,(FeO)_2,SiO_2$ and CaO,SiO_2 are perfectly miscible in all proportions, non-isomorphous, and incapable of combining chemically with each other.

Passing along the same line from K to O, we commence a descent; but lack of data prevents the formation of any definite conclusions.

---

* Bakhuis-Roozeboom, speaking of the ways in which "a liquid phase formed by two components may solidify," says "the application of the phase-doctrine is so general, that it matters not whether we start from a liquid phase built up from water and a salt, or from two salts fused together, or from two silicates, or from two metals, or from iron or carbon."—*Jour. I. and St. Inst.*, vol. lviii. (No. II. of 1900), p. 311.

† Isomorphous mixtures of two substances have a freezing-point curve which approximates a straight line, but is usually slightly bowed. Such curves, consequently, may give minima only when the freezing-points of the two substances are very nearly the same. I should feel surer that the line LMK represented non-isomorphous mixtures if the minimum were lower.

By a line drawn through the third vertex B and the point K, the leg AO is intersected in Z, corresponding to the chemical compound $CaO,(FeO)_2$. Going from K to Z there seems to be a minimum at 1180° C; but lack of data prevents the formation of any definite conclusions. In going from K to B, we descend as far as the data extend; but no conclusions are drawn. Nor can we regard the data as quite sufficient to warrant conclusions as to the mutual relations of $(FeO)_2,SiO_2$ with either FeO or SiO_2.

Looking over the whole field, it appears that all the slags contain $CaO,(FeO)_2,SiO_2$, probably mixed:

In the triangle LKB, with $(FeO)_2,SiO_2$ and SiO_2,
In the triangle BKT, with SiO_2 and CaO,SiO_2,
In the triangle TKA, with CaO,SiO_2 and CaO,
In the triangle AKZ, with CaO and $CaO,(FeO)_2$,
In the triangle ZKO, with $CaO,(FeO)_2$ and FeO, and
In the triangle, OKL, with FeO and $(FeO)_2,SiO_2$.

This may be otherwise expressed by saying that the quadrilateral LBTK has chemically uncombined silica throughout its extent, and so gives acid slags; that the quadrilateral KTAZ has chemically uncombined lime throughout its extent, and so gives basic slags; and that the quadrilateral KZOL has chemically uncombined ferrous oxide throughout its extent, and so gives comparatively neutral slags.

A means is thus afforded of giving rational results of a slag analysis, in which values should be given for three of the following compounds:

$CaO,(FeO)_2,SiO_2$; CaO,SiO_2; $CaO,(FeO)_2$; $(FeO)_2,SiO_2$; CaO; FeO; and SiO_2.

Take, for example, in triangle AKT, the

	CaO	FeO	SiO_2.	
Basal Slag (C), ...	32.00	35.90	32.10	
Subtract CaO, $(FeO)_2$, SiO_2 21.55 55.24 23.21 equivalent to	14.01	35.90	15.08	= 64.99 per cent.
Leaving	17.99	0.00	17.02	
Subtract CaO, SiO_2 48.15 51.85 equivalent to . .	15.81		17.02	= 32.83 "
Leaving CaO, 100.00 " " . .	2.18		0.00	= 2.18 "
		Total,	.	100.00 "

An alloy of non-isomorphous metals at the maximum and minimum points of its freezing-point curve has but one *structural* constituent (composed of one or more chemical compounds—one at the maxima, more at the minima) and but one freezing-point, while at intermediate positions the alloy has more than one structural constituent and a freezing-point corresponding to each constituent. It follows that, at temperatures between the upper and lower freezing-points of such an alloy, one structural constituent is solid and another liquid, and the mass as a whole is, in consequence, pasty. If the temperature of the alloy is below all the freezing-points, the alloy is solid; if above all the freezing-points, the alloy is liquid. How far this principle may apply to slags cannot be told without investigation. From analogy, we may expect an abrupt change from solid to liquid at the maxima L, K, T, Z, and *vice versa* at the minima M, S, N, R. In intermediate regions, especially half-way, a pasty condition may be expected at temperatures not sufficiently elevated. As an illustration, some of the points where, from the analogy, pastiness may be expected are:

CaO, 5; FeO, 67; SiO_2, 28.
CaO, 30; FeO, 42; SiO_2, 28.
CaO, 18; FeO, 48; SiO_2, 34.

The latter portion of Prof. Hofman's paper treats of the replacement of the slag-constituents by chemically equivalent portions of other oxides; successive eighths of one of the three constituents being removed from, and a corresponding portion of the replacing oxide being added to, a basal slag of the composition SiO_2, 32.10; FeO, 35.90; CaO, 32.00. The result is an alteration of the formation-temperature, due to the two causes, *removal* and *addition*. No attempt is made by Prof. Hofman to analyze the temperature-alteration into the effects of these separate causes. Such an analysis is made possible without further experimentation by the employment of the tri-axial diagram.

Take, for example, the replacement of six-eighths of the CaO by a chemically equivalent amount of BaO (Fig. 7). The basal slag forms at 1150° C. With six-eighths of the CaO removed, its composition becomes CaO, 10.53; FeO, 47.24; SiO_2, 42.24. From Fig. 6, we find that a slag of this composition forms at

1045° C.—a fall of 105° C. due to the *removal* of CaO. Then, with BaO *added*, the formation-temperature falls 60° C. further to 985° C., as given by Prof. Hofman—a total fall of 165° C.

Fig. 7

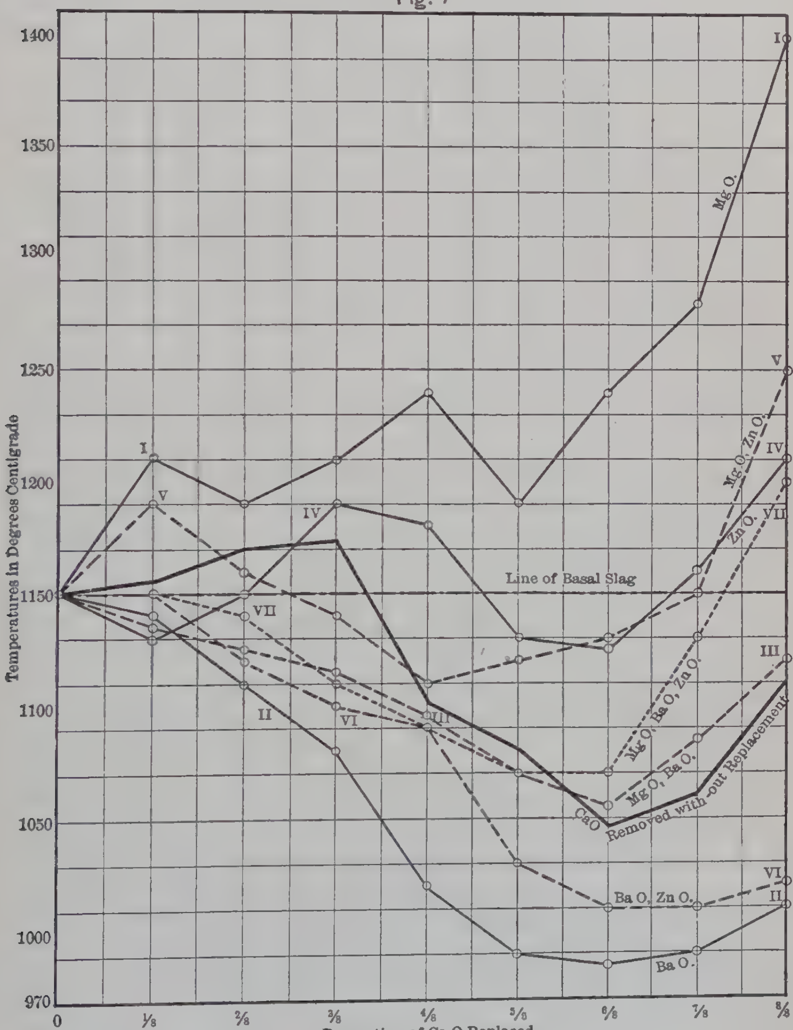


Diagram Showing Effect of Replacement of Ca O by Mg O, Ba O and Zn O.

(Being Fig. 9 of Prof. Hofman's Paper, *Trans.*, xxix., with additions.)

If, instead of BaO, MgO had been added, the formation-temperature would have risen to 1240° C.—a rise of 195° due to the *addition* of MgO, as compared with a fall of 60° C. due to

addition of BaO; or a net rise of 90° above the formation-temperature of the basal slag, due to the replacement of CaO by MgO, as compared with a total fall of 165° C., due to the replacement of CaO by BaO. It is thus seen that while, *with these proportions*, BaO produced nearly twice as great an alteration in formation-temperature as MgO, when *replacing* CaO; nevertheless MgO, *added* to a charge in a furnace, would pro-

Fig. 8

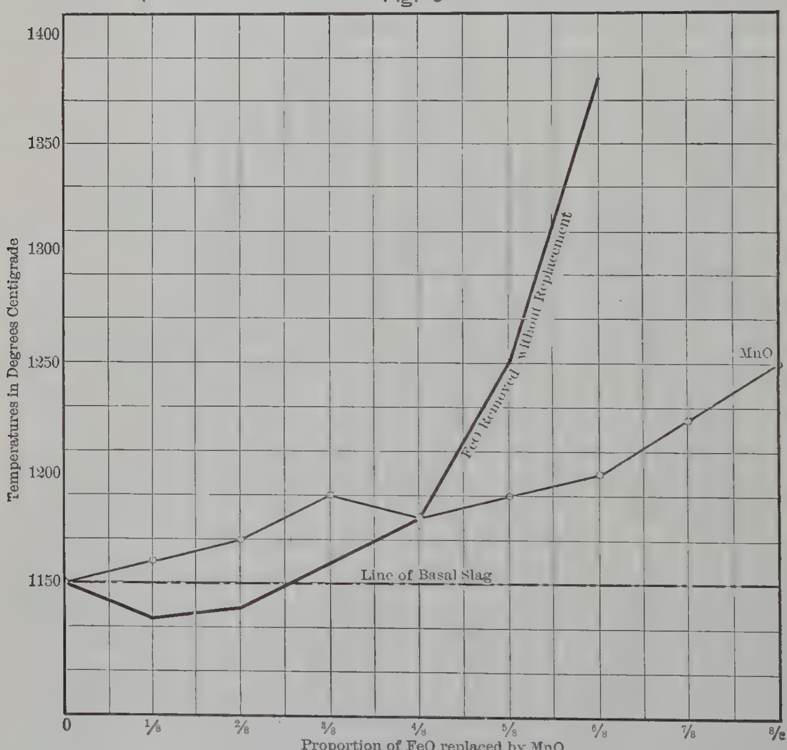


Diagram Showing Effect of Replacement of Fe O by Mn O.

(Being Fig. 8 of Prof. Hofman's Paper, *Trans.*, xxix., 704, with additions.)

duce three times as great a temperature-alteration as an equivalent addition of BaO.

The compositions of the slags with the successive eighths of some one constituent removed are shown in Fig. 6 by the small circles in three lines radiating from the basal slag (C). It will at once be evident that the sharp rise in temperature to the right of the basal slag in Fig. 6 cannot but have a profound effect on the character of the replacement-curves for FeO and

SiO_2, and an inspection of Figs. 8 and 9 (corresponding to Figs. 8 and 10 of Prof. Hofman's paper) shows rises in temperature to the right in all cases. If the basal slag had been chosen further to the left, with, say 10 to 20 CaO, this feature of the replacement-curves would in all probability have been

Fig. 9

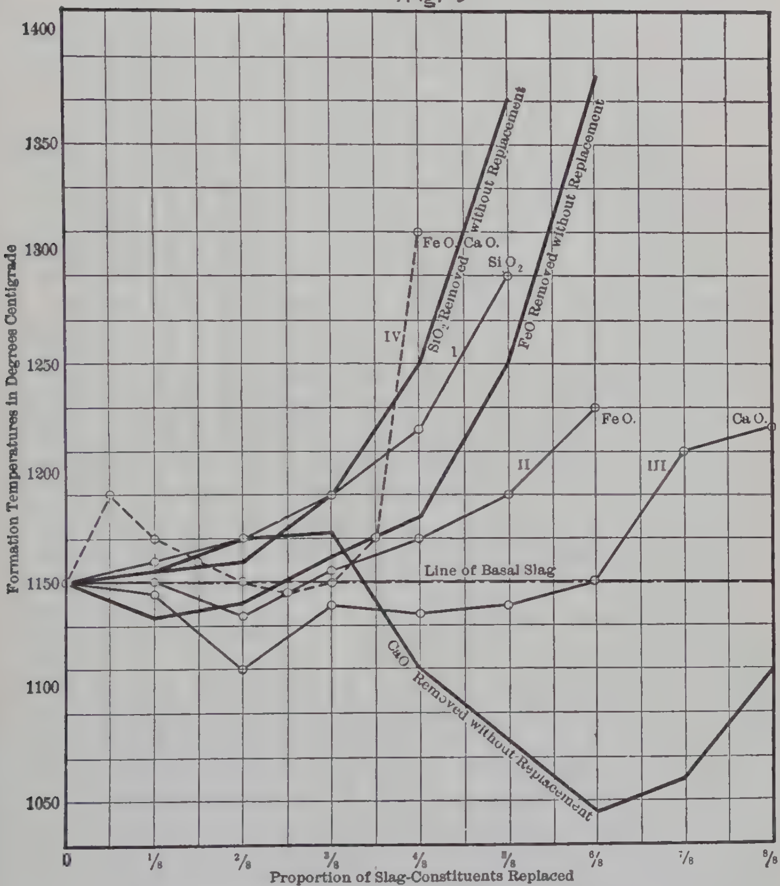


Diagram Showing Effect of Replacement of Slag-Constituents by Al_2O_3

(Being Fig. 10 of Prof. Hofman's Paper, *Trans.*, xxix., 710, with additions.)

very different. In Figs. 7, 8 and 9, I have reproduced Figs. 8, 9 and 10 of Prof. Hofman's paper, with the addition of curves showing the effect of removal only. They will make it easier to understand the relative fluxing or refractory natures of the several replacing oxides.

Lime-Magnesia-Silica.

Professor Akerman has determined* the "total heat of solidification" of the 1.5, 2.0, 2.5, and 3.0 silicates of lime and magnesia. While, as explained below, under the head of lime-alumina-silica, his results can be taken as only approximately quantitative, they throw light on the mineralogical composition of the slags, and are most nearly accurate in the neighborhood of the maxima and minima—the regions most significant for this discussion.

If we assume that specific heats and latent heats are nearly the same for all the region investigated, then differences in the "total heats of solidification" can be attributed only to differences in the freezing-temperatures. The attempt to translate the "total heats of solidification" into freezing-temperatures would be fraught with considerable difficulty, and will not be made here.

For our purpose, in using Prof. Akerman's results, small percentages of Al_2O_3, MnO, and FeO, aggregating from 1.10 to 1.98 per cent., are disregarded; and the remaining constituents, CaO, MgO, and SiO_2, are re-calculated so that their total shall be 100 per cent.

The data thus obtained are plotted in Fig. 10. "Isocals"† are drawn 10 calories apart, and show the amount of heat in calories given up by each gramme of slag in solidifying and cooling to 0° C.

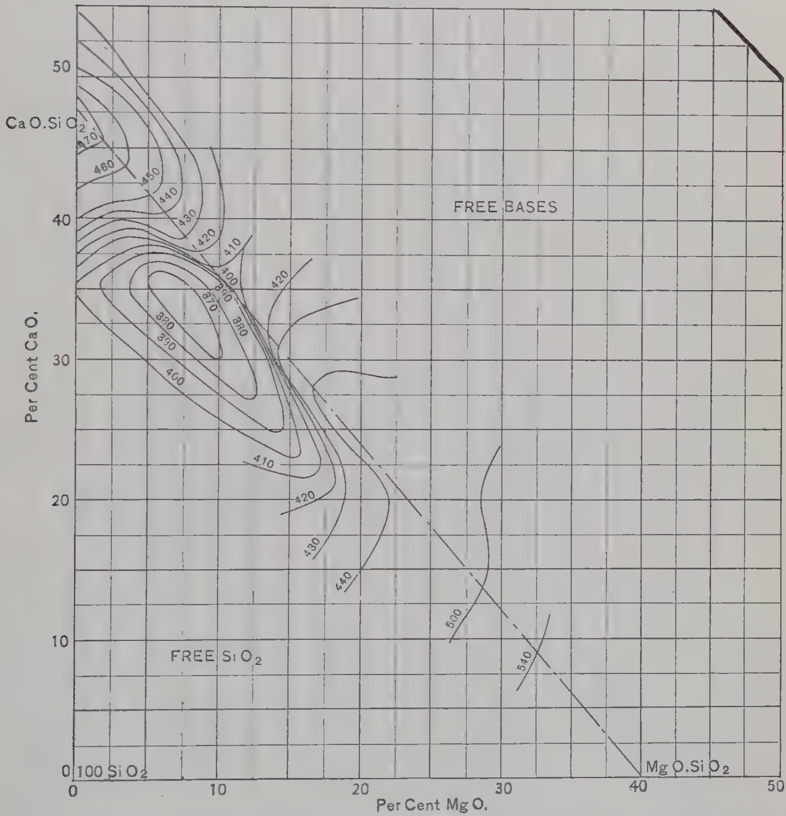
There is a maximum of about 480 calories at CaO, 48.15, SiO_2, 51.85 per cent., corresponding to the chemical compound CaO,SiO_2. A second maximum is indicated, but not reached by the data, at MgO, 40.06 per cent., SiO_2, 59.94 per cent., corresponding to the chemical compound MgO,SiO_2. It does not appear likely that there are any other maxima save those of the three original constituents, CaO, MgO, and SiO_2. A binary minimum occurs between SiO_2 and CaO,SiO_2 with 35 per cent. CaO. A minimum is also indicated between CaO,SiO_2 and CaO somewhere above 55 per cent. CaO. A minimum occurs about one-fourth of the distance from CaO,SiO_2 to MgO,-SiO_2, where the composition is about CaO, 35; MgO, 10.5; SiO_2,

* *Jernkontorets Annaler*, 1886, pp. 1–77; *Stahl und Eisen*, 1886, pp. 281 and 387.
† H. M. Howe, *Trans.*, xxviii., 346.

54.5. A ternary minimum, between SiO_2, CaO,SiO_2, and $MgO,$-SiO_2, occurs near CaO,SiO_2, and is elongated in direction parallel to the line of the mixtures of the two silicates.

It appears from an inspection of the diagram that the slags are neutral when the constituents are in the ratio indicated by

FIG. 10.



"Total Heat of Solidification" of CaO-MgO-SiO_2 Slags. (R. Åkerman, 1886.)
NOTE.—The numbers within the diagram indicate calories per gramme of slag.

the formula $R''O,SiO_2$, are acid when the silica exceeds this ratio, and have free bases when the lime and magnesia total exceeds this ratio.

An interesting confirmation of these views is found in a paper presented to the Institute in 1899 by O. R. Foster on "The Relative Desulphurizing Effect of Lime and Magnesia

in the Iron Blast-Furnace."* Mr. Foster treated 100-gramme portions of an iron containing 0.56 per cent. sulphur by heating in graphite crucibles for three hours each, with various lime-magnesia-silica slags. His results are given in the following two tables:

TABLE I.—*Sulphur Contents of Resultant Iron.*

Experiment No.	1.	2.	3.	4.
Ox. ratio of................	1 : 1.5	1 : 2	1 : 2.5	1 : 3
Silicate.	Sulphur. Per cent.	Sulphur. Per cent.	Sulphur. Per cent.	Sulphur. Per cent.
Low MgO...................	0.061 0.061	0.336 0.337	0.377 0.361	0.385 0.367
Medium MgO..............	0.255 0.254			
High MgO..................	0.166 0.198 0.123	0.315 0.325	0.456 0.453	0.267 0.277

The ratio given in the upper line of the table is that of oxygen in bases to oxygen in acid (SiO_2).

TABLE II.—*Percentages of CaO and MgO Corresponding to Table I.*

Experiment No.	1.	2.	3.	4.
Ox. ratio of................	1 : 1.5	1 : 2	1 : 2.5	1 : 3
Silicate.	Per cent.	Per cent.	Per cent.	Per cent.
Low MgO...................	CaO 40.19 MgO 12.85	CaO 34.75 MgO 11.11	CaO 34.02 MgO 7.00	CaO 35.33 MgO 2.31
Medium MgO..............	CaO 32.06 MgO 19.77			
High MgO..................	CaO 23.51 MgO 27.06	CaO 27.63 MgO 17.04	CaO 15.42 MgO 22.20	CaO 29.44 MgO 7.06

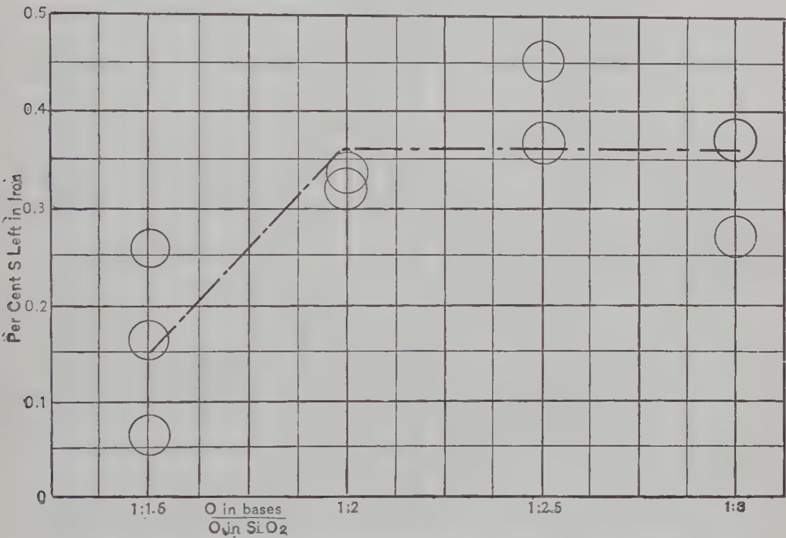
These tables show that the silicates CaO,SiO_2 and MgO,SiO_2 remove an appreciable portion of sulphur in a neutral slag (Exp. No. 2, Ox. ratio 1 : 2); that this power is little, if any, lessened by free silica (Exps. Nos. 3 and 4, Ox. ratios 1 : 2.5 and 1 : 3); and that a small amount of free base very greatly

* *Trans.*, xxix., 562.

increases the power of removing sulphur, (Exp. No. 1, Ox. ratio 1 : 1.5.) These facts are more strikingly exhibited by the plotted data. (Fig. 11.)

The plot of "total heats of solidification" (Fig. 10) also throws light on the results presented by Frank Firmstone, in 1894,* on "Magnesia and Sulphur in Blast-Furnace Cinder."

FIG. 11.



Removal of Sulphur by Lime-Magnesia-Silica Slags. (O. R. Foster, 1899.)

With a change from limestone to dolomite, the cinder changed as follows:

	Cinder before Oct. 5, 1891.	Cinder after Oct. 5, 1891.	
	Per cent.	Per cent.	Per cent.
SiO_2,	39.95	37.82	38.37
Al_2O_3,	5.48	4.05	3.98
CaO,	47.39	35.46	35.18
MgO,	5.38	19.88	19.48
FeO,	0.94	0.74	1.22
CaS,	not det.	1.82	1.53
$\frac{\text{O in } SiO_2}{\text{O in bases}}$ =	1.17	1.01	1.04

It appears that before October 5th he was in rather unpleasant proximity to the maximum "total heat of solidification" belonging to the compound CaO,SiO_2, and after October 5th he was just across the minimum, and not liable to climb to a

* *Trans.*, xxiv., 498.

higher temperature. Moreover, he had practically changed from a two-component slag to a three-component one. *Usually every additional component, if not in too great amount, tends to lower the temperature of fusion.* A further increase in magnesia in this case would probably have been harmful. Finally, he increased the amount of free bases slightly. He says:

"The dolomite has been regularly used ever since; and a comparison of the iron made over the whole period before its use, with that made since, . . . leaves no doubt that the iron is both lower in sulphur on the average, and far more regular in this respect, when the flux is dolomite, in spite of a very much lower percentage of lime in the cinder."

In the manufacture of open-hearth steel, it may be noticed that, after passing a certain limit, each addition of lime to the slag has much greater efficacy in removing sulphur than had previous additions of equal weight.* This indicates the superiority of CaO over CaO,SiO_2.

Lime-Alumina-Silica.

More data are available for the lime-alumina-silica slags than for either of the two preceding cases; but, perhaps owing to the abundance, the evidence is somewhat conflicting. It will be easier to consider first the binary mixtures.

Lime-silica mixtures have been investigated by Akerman † also, in connection with the "total heat of solidification" of lime-alumina-silica slags (Fig. 12). The result is the same as obtained in the lime-magnesia-silica investigation,—viz., a maximum "total heat of solidification" of about 480 calories per gramme, corresponding to the chemical compound CaO,SiO_2, and lower values with either increase or decrease of lime.

Alumina-silica formation-temperatures are shown by Seger‡ in a diagram, representing the fusibility of alumina-silica and of kaolin-silica mixtures, expressed in Seger-cone numbers. The diagram and description are reproduced by Hofman and Demond.§ The upper curve shows mixtures of alumina and silica, the lower of Zettlitz kaolin and silica. The abscissæ give the number of molecules of SiO_2 to one of Al_2O_3. The

* Oral communication from Wm. A. Leonard.

† *Stahl und Eisen*, 1886, pp. 281 and 387.

‡ *Thonindustrie-Zeitung*, 1893, p. 391.

§ *Trans.*, xxiv., 43, 45.

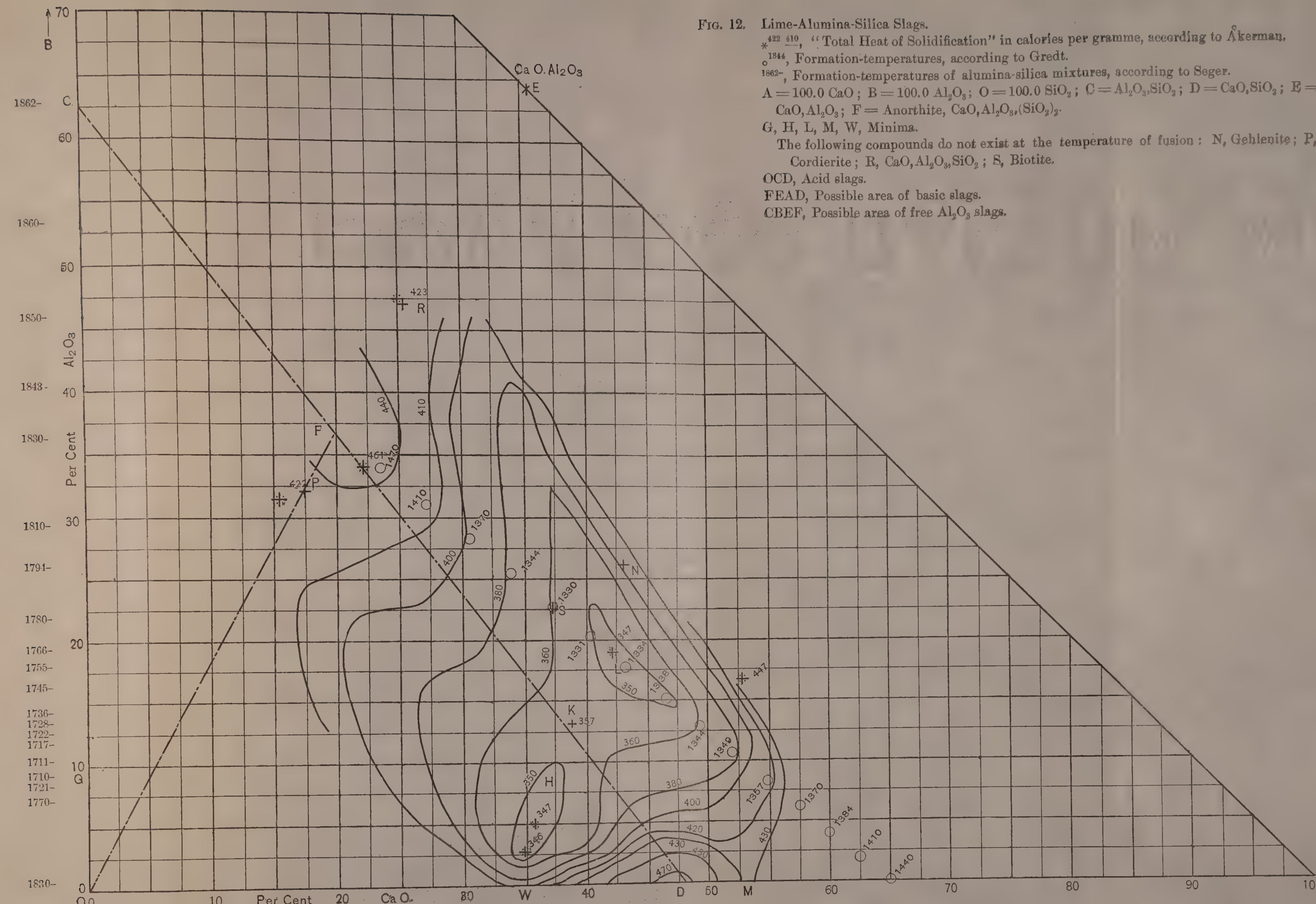


FIG. 12. Lime-Alumina-Silica Slags.

$*^{422}\ \underline{410}$, "Total Heat of Solidification" in calories per gramme, according to Åkerman.

$\circ^{1344}$, Formation-temperatures, according to Gredt.

^{1862}–, Formation-temperatures of alumina-silica mixtures, according to Seger.

A = 100.0 CaO; B = 100.0 Al_2O_3; O = 100.0 SiO_2; C = Al_2O_3,SiO_2; D = CaO,SiO_2; E = CaO,Al_2O_3; F = Anorthite, CaO,Al_2O_3,$(SiO_2)_2$.

G, H, L, M, W, Minima.

The following compounds do not exist at the temperature of fusion: N, Gehlenite; P, Cordierite; R, CaO,Al_2O_3,SiO_2; S, Biotite.

OCD, Acid slags.

FEAD, Possible area of basic slags.

CBEF, Possible area of free Al_2O_3 slags.

formula for dehydrated pure kaolin $Al_2O_3,(SiO_2)_2$ is very nearly approached by ignited Zettlitz kaolin; but there are small percentages of impurities, whose effect would be to lower the fusion-temperature. Seger cones 28 to 35 are made in accordance with the left-hand branch of the kaolin-silica curve. Prof. Hofman says:

"The cones are, however, not true pyrometers; since the change of a mixture into a chemical compound by heating is not a function of temperature alone, but depends also upon the manner of firing, the time given, and the form of the furnace. . . . The temperatures given in the table correspond pretty closely to the control-measurements with the Le Chatelier pyrometer, so long as the heating is carried on slowly."

The "table" referred to is Hecht's standardization of the Seger cones* against the Le Chatelier pyrometer. It seems to me that the change is not from "a mixture into a chemical compound," but, as I shall attempt to show below, is, in the case of cones 28 to 35, a formation in the mixture of the chemical compound Al_2O_3,SiO_2, which remains mechanically mixed, or in mutual solution, with the excess of SiO_2.

In Seger's diagram, the abscissæ represent the ratio of the number of molecules of SiO_2 to the number of molecules of Al_2O_3. Owing to this peculiar system, the plot is rather misleading. It seems to give all proportions, while really there is given no numerical value between 50 and 100 per cent. Al_2O_3 in the alumina-silica mixtures. Again, if the system were consistently carried out, 100 per cent. SiO_2 would have to be plotted at the ratio infinity; on the diagram it is at 25.5. The apparent convergence of the kaolin-silica and alumina-silica curves is misleading; for the two curves should converge only at infinity.

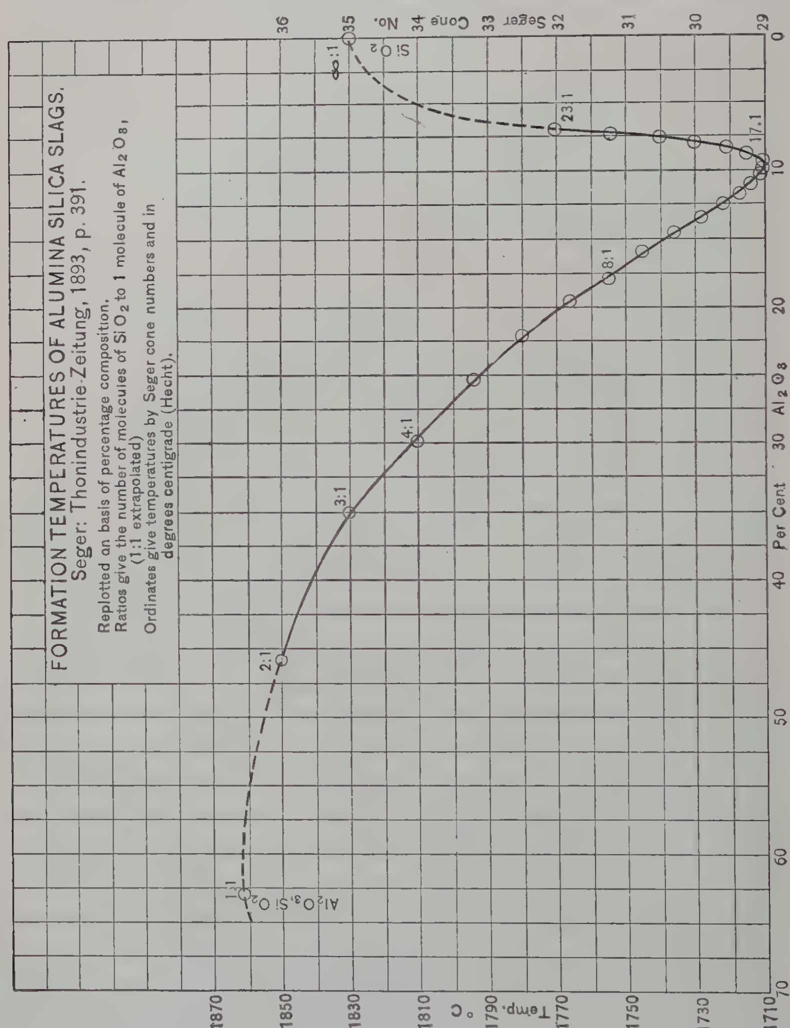
To show Seger's results by a more common method, I have replotted (Fig. 13) his alumina-silica curve with the abscissæ showing the composition in percentages of the total weight of the mixtures. Since, according to Hecht's standardization, all the Seger cones hereabouts differ 20° C. from each other, it is possible to let the ordinates represent both centigrade degrees and Seger cone numbers at the same time. The curve has been prolonged to show a maximum corresponding to the

---

* *Trans.*, xxix., 687.

chemical compound Al_2O_3,SiO_2. If the compound exists at these temperatures, there must be a maximum freezing-temperature corresponding to it. Josef Morozewicz, in an "Experimental Investigation of the Formation of Minerals in Magma,"*

FIG. 13.



found that "Corundum (Al_2O_3), spinel ($R''O,Al_2O_3$), sillimanite (Al_2O_3,SiO_2) and cordierite ([H,Mg,Fe,Al]O,SiO_2) in magmas supersaturated with alumina, are the first products of crystallization. Spinel and sillimanite crystallize before corundum."

* *Tschermak's Mineralog. und Petrogr. Mitth.*, Vienna, Austria, xviii., pp. 1–90; also pp. 105–240. Also reviewed by T. A. Jagger, Jr., in *Jour. of Geol.*, Chicago, vii., p. 300.

The compound seems to be quite stable at all temperatures, persisting, though the form changes. According to Vernadsky, both andalusite (orthorhombic) and cyanite (triclinic) are transformed at 1320°–1380° into sillimanite (orthorhombic) with the disengagement of heat.* It seems safe to make a provisional assumption that there is a maximum freezing-point corresponding to the chemical compound Al_2O_3,SiO_2, as well as to SiO_2 and Al_2O_3.

Lime-alumina mixtures are not represented by any thermal data. The existence of a lime-spinel (CaO,Al_2O_3) is, however, quite generally accepted, both on mineralogical examination† of frozen slags and on analytical separation.‡

Ternary Mixtures.—In the binary mixtures between the primary components lime-alumina-silica slags resemble lime-ferrous oxide-silica slags. CaO,SiO_2 occurs in both—$CaO,(FeO)_2$ probably in the latter; CaO,Al_2O_3 probably in the former; $(FeO)_2,SiO_2$ in the latter; Al_2O_3,SiO_2 probably in the former. If the analogy were to extend to ternary mixtures, CaO,Al_2O_3,SiO_2 might be expected, corresponding to $CaO,(FeO)_2,SiO_2$; but such data as are available oppose such an assumption. Akerman's "total heats of solidification" reach a maximum of 461 calories per gramme at a point corresponding very closely to anorthite, $CaO,Al_2O_3,(SiO_2)_2$. The proportions for Vogt's§ gehlenite $(R''O)_3,Al_2O_3,(SiO_2)_2$ are shown by Hecht's "total heats of solidification" to possess no maximum corresponding to the existence of a definite chemical compound. All the data available for these slags are plotted in Fig. 12.

It will be seen that for the alumina-lime mono-silicates Akerman has determined "total heats of solidification," and Paul Gredt‖ formation-temperatures. The latter were determined by means of Seger cones, and the temperatures here given have been revised by me to accord with Hecht's standardization of the Seger cones. To show the relation between "total heat of solidification" and formation-temperature, the two sets

* "System of Mineralogy," Dana (1899), p. 499.

† *Jour. of Geol.*, vii., p. 300; *Jour. I. and St. Inst.* (1900), lviii., [2], 285.

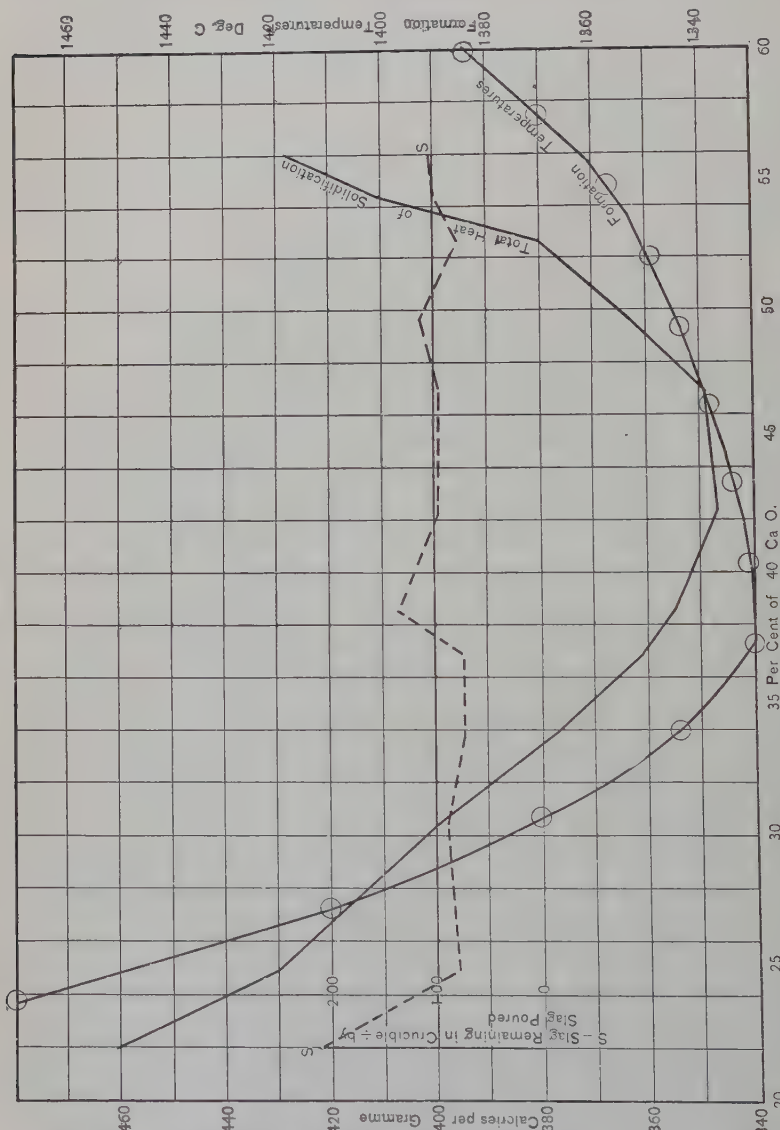
‡ *Iron* (1880), xvi., 292; *Trans.* (1894), xxiv., 503, Frank Firmstone.

§ "*Studien over Slaggen;*" *Bihang till k. Svenska Vet. akad. Handl.*, vol. ix., No. 1; "*Om Slaggers af Sammansättningen beroende Kristallisations förhällanden,*" *Jernkontorets Annaler*, 1885; *Beiträge zur Kentniss der Mineralbildung, Kristiania*, 1892.

‖ *Stahl und Eisen*, 1889, p. 756.

of results are plotted in Fig. 14. The abscissæ represent per cent. of lime, the ordinates give calories and degrees centigrade. Gredt's work is seen to be very consistent, while Akerman's curve is irregularly angular.

Fig. 14.



Formation-Temperatures of Alumina-Lime Mono-Silicates, by Paul Gredt, Revised according to Hecht.
"Total Heats of Solidification," by R. Åkerman.

As has been already stated, a slag consists of only one structural constituent at maxima (definite chemical compound) and at minima (eutectic mixture). Between maxima and minima, when the chemical compounds are not isomorphous, there are

two or more structural constituents. The freezing-point curves give the temperatures at which the least fusible constituents begin to solidify. Melting-point curves are lower, and, since it is difficult in many cases to determine when fusion begins, are less valuable. The maxima are identical with the freezing-point curve maxima. Formation-point curves lie somewhat above melting- and freezing-point curves, and shift somewhat, according to the chemical condition of the unfused ingredients.* If Akerman had melted a slag in a perfectly refractory crucible, allowed it to cool slowly, and then, at the very instant when the first particle of slag commenced to freeze out, emptied the slag into his calorimeter, he would have had results strictly comparable with freezing-points, provided we assume specific and latent heats to be the same for all slags. But instead of this, at one time 50.51 grammes was run into the calorimeter, and 106.1 grammes frozen slag retained in the crucible; again, 103.29 grammes was poured and 86.4 grammes retained; ordinarily about half was poured. Since the freezing-temperature of a mixture is lowered by the removal of its least fusible constituent, it seemed likely that his "total heat of solidification" would be lowered considerably when much slag was allowed to freeze out in the crucible, or raised when a larger portion than usual was run into the calorimeter. Just the contrary is shown in Fig. 14 by an auxiliary plot, in which ordinates represent the ratio of slag remaining to slag poured. I could form hypotheses to reconcile the theory and facts, but their foundation would be guesswork. The trouble would not affect a maximum or a minimum, as at such points the whole slag freezes at one temperature. At maxima and minima the "total heat of solidification" represents latent heat of fusion plus the product of the specific heat of the solid into the freezing temperature. It is quite proper. But at other points it is a misnomer of indefinite meaning; for a part of the slag is not cooled down to its freezing-point, and another part has already given up its latent heat of fusion, and cooled somewhat below a shifting freezing-point; and there is no fixed relationship between these two parts.

Prof. H. M. Howe used these data of Akerman's to illustrate his paper on the tri-axial diagram,† and his plot was nearly the

* See Seger's diagram, *Trans.*, xxiv., 43.

† *Trans.*, xxviii., 346.

same as mine, except that he connected the two minima H and L (Fig. 12) in one wasp-like figure. Now the line D F, representing mixtures of CaO,SiO_2 with $CaO,Al_2O_3,(SiO_2)_2$ cuts his figure in two; for it is all along a binary ridge separating two more complex regions, and the addition of a third constituent tends to lower freezing- or melting-points. Moreover, Akerman's determination at the waist of the figure (K, Fig. 12) is 357—7 calories higher than the isocal 350 calories surrounding the minimum region in Prof. Howe's diagram.

All lime-alumina-silica slags probably contain the compound $CaO,Al_2O_3,(SiO_2)_2$, mixed in the triangle D O F (Fig 12) with CaO,SiO_2 and SiO_2, and in the triangle F O C with SiO_2 and Al_2O_3,SiO_2. In other regions of uncertain limits may be found Al_2O_3, CaO,Al_2O_3, CaO, and, less probably, other compounds. CaO,Al_2O_3,SiO_2, $(CaO)_3,Al_2O_3,(SiO_2)_3$, cordierite, and gehlenite probably do not exist in the liquid slags.

Other Slags.

Many common slags have been left out of this discussion because of the absence of thermal data concerning them. No such data have been given concerning the extremely important constituents CaS, P_2O_5, CaF_2, Na_2O, and K_2O.

II. The Relation Between Mineralogical Examination of Frozen Slags and Thermal Examination of Molten Slags.

There is a tendency among most investigators of slags to assume that a molten slag has the same chemical composition as the frozen slag; and it may be noticed that in the preceding discussion no provision is made for olivine $(MgO)_2,SiO_2$; monticellite, CaO,MgO,SiO_2; augite $(CaO, MgO),SiO_2$; gehlenite $(R''O)_3,Al_2O_3,(SiO_2)_2$, etc., which have actually been found in frozen slags. While the discovery of crystals of definite chemical composition in a frozen slag indicates the *possibility* of the existence of that chemical compound in the molten slag, it does not prove any such existence.

Thus, while microscopical, chemical, and thermal examination of steel shows it to be a mixture of iron (Fe) and the carbide Fe_3C, the freezing-point curve of the molten metal corresponds to a solution of graphite (C) in iron (Fe). The mixture, then, must alter in solid solution to form the compound Fe_3C, which does not exist in the molten bath. The theory of this change

is summarized in an article by A. Stansfield on "The Present Position of the Solution Theory of Carburised Iron."*

Heycock and Neville† have found a similar case in the gold-aluminum alloys, which is thus reviewed by Wilhelm Ostwald:

"Between G and H ($AuAl$ and $AuAl_2$ on the freezing-point curve) the microscopic investigation shows undoubtedly that the solid alloy is composed of three different solid materials. This fact, apparently contrary to the phase-law, is explained in the following manner: That first an unstable substance, X, exists, whose composition is unknown. Then is formed the stable purple violet alloy; the velocity of transformation of the first crystals is, however, not sufficient for them to disappear completely, and there still remain, therefore, residues from them, together with two stable substances, since each grain of the compound X is surrounded by an envelope of $AuAl_2$. Because of such phenomena of change, quickly cooled alloys often show totally different properties from other mixtures of exactly the same composition, which have been made to cool very slowly. This fact is of great importance for the interpretation of geological phenomena."

Besides changes in solid solution, there are those which take place during the process of solidification.

Stansfield says:

"Several analogous cases are known among aqueous saline solutions, in which the dissolved salt can separate in two or more states; either anhydrous (corresponding to the graphitic state of carbon), or containing water of crystallization (corresponding to Fe_3C). In some of these cases either form of the salt can be made to separate at will from the solution by placing in it a crystal of the desired variety."

Small impurities may induce an unnatural crystallization. Morozewicz, in one of his synthetic experiments on the formation of igneous rocks (liparite), found the addition of a small amount (1 per cent.) of tungstic acid, hitherto considered an unessential component, to be essential to securing the desired crystallization.

Again, it is possible that some of the complex crystals found in furnaces or in natural rocks are really eutectic mixtures; for some metallic eutectic alloys seem to possess a decided crystalline tendency.

Vogt appears to have found such a case‡ in the lime-magnesia-silica slags. Morozewicz says:

"We must consider as one of the most important results of Vogt's work the conditions determined by him for the separation of the different metasilicates in

* *J. I. and Steel Inst.* (1900), lviii., [2], 317; *Metallographist* (1900), iii., [4], 300.

† *Philos. Trans.* (1900), cxciv., 201–232. *Z. für phys. Chemie* (1901), xxxvii., [3], 374.

‡ *Tschermak's Mineralog. und Petrogr. Mitth.* (1898), xviii., [23], 109.

slags free from alkalis and ferric oxide and containing small amounts of alumina. When the ratio is $CaO : MgO = 1$, there is formed monoclinic augite (extinction: 37—40 degrees); it crystallizes also with other ratios of $CaO : MgO$, which may reach 3 : 1; then, however, the crystals are smaller; when $CaO : MgO = 1 : 3$ or still more, instead of augite there separates out rhombic pyroxene (enstatite, or—in case FeO is present—hypersthene); finally, in slags where the CaO-content is greater than the ratio $CaO : MgO = 3 : 1$, there separates out for the most part, or exclusively, the hexagonal metasilicate of calcium $Ca\,SiO_3$."

It seems to me very probable that monoclinic augite is the eutectic mixture between CaO,SiO_2 and MgO,SiO_2, or that it is formed by some transformation of the solid eutectic mixture below its freezing-point.

III. Conclusions.

The behavior and rational chemical composition of slags are probably to be explained by variation in the conditions of equilibrium at different temperatures, investigated in the light afforded by modern theories of solution. The freezing-points of mixtures of chemically pure substances should be determined by cooling curves if possible, and the conclusions derived therefrom should be verified by microscopic examination. The electrical resistance, formation-temperatures, and precisely defined "total heats of solidification" will also be of value.

The system of investigation should be about as follows: Having, say, four substances, A, B, C, and D (CaO, CaS, SiO_2, etc.), first determine very carefully the curves for all possible binary mixtures. Certain maxima, corresponding to definite chemical compounds (A_mB_n, A_sC_t, etc.), will be found. The curves should then be determined for all possible binary mixtures between the substances A, B, C and D and the compounds A_mB_n, etc.; also between pairs of compounds. These will probably give all the ternary compounds. To complete the investigation of the ternary mixtures, and determine the ternary minima, determinations should be made more widely apart on the hitherto uncovered region. The quaternary compounds and mixtures may then be similarly determined.

Such an investigation will give more nearly than any means hitherto employed an exact idea of the conditions existing in liquid slag.

Before concluding, I must again call attention to the assumption made that formation-temperatures are very close to melting- or freezing-points. Much of this discussion is based on that assumption. Furthermore, while conclusions regarding the

character of the slags within the limits of the data are regarded as warranted in all cases, conclusions regarding slags outside the region investigated must be regarded merely as predictions.

In conclusion, I will express the hope that this paper may help to make the advantages of the tri-axial diagram better known, and its application easier. I believe this method of discussing results will prove to be of great practical value, and applicable not only to slags, but also to glasses, pottery, enamel, cement, stoneware, bricks, and other mixtures.

Supplementary Notes.

The following atomic and molecular weights have been used in the foregoing paper:

O,	16.000	FeO,	71.9
Fe,	55.9	Fe_2O_3,	159.8
Si,	28.4	SiO_2,	60.4
Ca,	40.1	CaO,	56.1
Al,	27.1	Al_2O_3,	102.2
Mg,	24.36	MgO,	40.36

In preparing the latter part of this paper, I received much assistance from the summary given in the paper of Baron Jüptner von Jonstorff, on "The Constitution of Slags, and the Part they Play in the Metallurgy of Iron."* His view of the subject, however, is so different from mine that I have not attempted to reconcile the two. For example, he says: "Free sesqui-oxides and free silica are *ab initio* excluded as slag constituents in silicate slags." Gehlenite $(R''O)_3,Al_2O_3,(SiO_2)_2$ plays a leading part in his slag computation, while it occurs in none of the slags I have discussed.

In the *Technology Quarterly* for December, 1901, I have published a paper in which the principle of the tri-axial diagram is extended to equations of the general form $x^m y^n z^p = k$, where m, n and p are any positive or negative, integral or decimal, real exponents. Application is made to the equation representing the behavior of a perfect gas, $\frac{PV}{T} = R$, and the various gas-engine cycles are illustrated by this new means. A point on the plot gives not only pressure, temperature, and volume, but also entropy and energy. The diagram is suitable for the rapid graphical computation of gas-engine problems. The title is "A Logarithmic Three-Variable Diagram."

* *Jour. I. and St. Inst.* (1900), lviii., [2], 276.

An Improved Form of Transit-Theodolite for Mining and Civil Engineers.

BY H. D. HOSKOLD, BUENOS AIRES, S. A.

(Mexican Meeting, November, 1901.)

THIS paper is presented in fulfillment of the promise made in my paper, "Remarks upon Surveying-Instruments,"* etc., and much of the material which would constitute an appropriate introduction here is omitted, because it has been already published by the Institute, in connection with my own contributions or those of Mr. Scott and others, in vols. xxviii. to xxxi. of the *Transactions*, and in the special Institute volume on Mine-Surveying Instruments.

In these preceding publications will be found, for instance, descriptions of the writer's "miner's transit-theodolite" of 1863,† and his later "angleometer,"‡ both of which were steps of the progress in engineering instruments and methods which originated in the work of Bourns, before 1842, on the "Box-Tunnel" of the Great Western railway in England, in which he had to make connections by direct telescopic sights down the shafts. About 1870 the writer devised a practical and much superior plan, and made detailed drawings for an instrument to meet all the conditions he had proposed prior to that year. The detailed plans were communicated to a celebrated optical firm in London; but, owing to their loss (in Paris or Germany, it is believed) and to other reasons, the matter was, for the time, allowed to lapse. Following upon Bourns's idea, my friend, the late Mr. Beansland, introduced, in 1856, a new system and a portable astronomical instrument.§ Such instruments, however, were neither common nor convenient, and did not come into general use among engineers.

---

* Present volume, p. 745. In the title there given to Mr. Hoskold's instrument, the word "canal" is a typographical error. It should be "civil."—R. W. R.)

† *Trans.*, xxix., 962, Fig. 74. ‡ *Ibid.*, 969, Fig. 76.

§ *Trans. N. of Eng. Inst. of M. E.*, vol. iv., pp. 267–273. See also *Trans.*, xxix., 975, Fig. 80.

More recently, Prof. E. H. Liveing has published a brief paper* on the subject, describing an astronomical transit-instrument of a similar class, with a stand of more open base, a telescope-aperture of 2.25 in., and a focal length of about 30 in.

From Prof. Liveing's description, and from the nature of the case, it follows that, for shaft-observations, an instrument of this type must be mounted carefully upon beams placed across the mouth of the shaft, and that if two illuminated marks, such as electric lights, are to be observed at the bottom, the whole instrument must be moved by hand, little by little, across the top, until the vertical spider-line intersects these two illuminated underground marks.†

Without further introduction, such as might be appropriately prefixed if the general subject had not been already so extensively treated in these *Transactions*, the new instrument of the writer will be described.

Hoskold's New Transit-Theodolite.‡

The general appearance of the instrument does not differ much from the ordinary English type, except in the length of the telescope and some other minor details. Nevertheless, there exist other important differences not easily distinguishable in the small figures (Figs. 2–9, pages 892–900).

1.—One of the practically important peculiarities of this instrument consists in the form of the central vertical axis, which is, as in ordinary cases, screwed to the under side of the horizontal vernier circle, but is made a great deal larger than is usual, to *allow it to be perforated* with a hole about *an inch in diameter* through its entire length; so that it has the form of a cylindrical axis, with a wide flange at its upper end, and with its exterior part turned slightly conical from end to end. At three places on the exterior surface of the axis, and equidistant one from the other, a wide band of metal is turned out a little

---

* *Trans. N. of E. Min. Eng.*, vol. xviii., Part I. (1869), pp. 65–71.

† Prof. Liveing, in the paper already referred to, describes a small movement of the axis of the instrument in azimuth, by means of a Y-screw; but this does not obviate the probable necessity of repeated lateral movements of the whole instrument by hand.

‡ British Patent, No. 15,521, dated Oct. 6, 1900.

below the general surface-level, so as to reduce its frictional surface to a minimum, when it is made to revolve in the usual exterior hollow vertical axis. This latter is, as is always the case, screwed to the under side of the horizontal divided circle, and revolves in a long vertical socket, which forms the central part of the triangular leveling apparatus, or base of the transit-theodolite. The friction upon the exterior rubbing-surface of the outer hollow vertical axis is also reduced in the same manner and for the same object as already described for the interior vertical axis. A hole corresponding to the one in the center of the internal axis is also made in the center of the vernier circle; so that, when the objective of the telescope is turned to look in a vertical direction, an observer can obtain a sight through the telescope and the center of the transit-theodolite,—*i.e.*, down through the vernier-circle and the central vertical axis, and so continuously down a vertical shaft. In this way, a line passing through two illuminated marks placed at the bottom of a shaft, and continued horizontally along a level-road or tunnel, can be reproduced upon the surface in the same direction with the greatest certainty, facility and accuracy.

In his paper on "The Evolution of Mine-Surveying Instruments,"* Mr. Scott refers to a nadir-instrument constructed by Hassler in 1824. But that instrument was only intended for setting the cross of the spider-lines "over a point in the aligned base-line, to ensure perfect parallelism in the subsequent setting of the metallic measuring-rod." The instrument had no internal revolving vertical axis. Nagel also invented a nadir-instrument some little time prior to 1878;† but, although this was employed to sight down a shaft, still it does not appear to have had any internal vertical axis, like a transit-theodolite, or to have been intended for general surveying. The instrument of Fig. 64,‡ constructed by Buff & Berger, was also a nadir-instrument, but unfit for general surveying.

Since commencing to write this paper, the writer has discovered that a patent was taken out in 1888, in Germany and the United States, for a transit-theodolite with a perforated vertical axis. This instrument is represented by Fig. 1, and from the description we learn that it was intended for a similar

* *Trans.*, xxviii., 698 (1898), Fig. 18. † *Ibid.*, 699, Fig. 19.
‡ *Trans.*, xxix., 941 (1899).

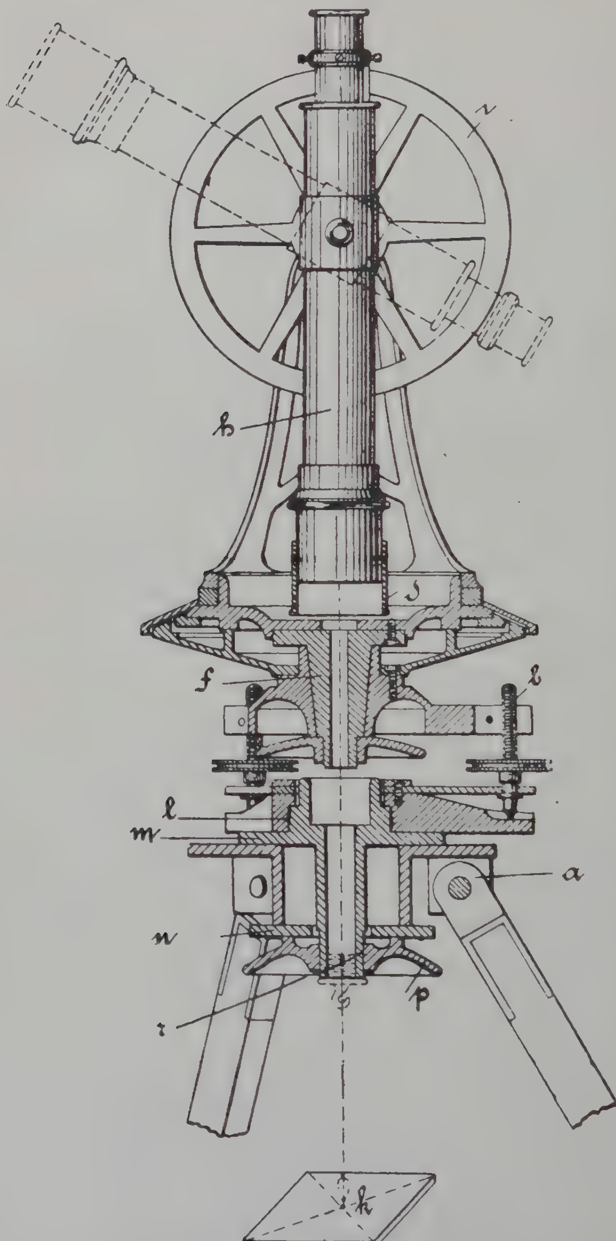
purpose to that of Mr. Scott's Fig. 18—*i.e.*, to enable the instrument to be centered, in ordinary surveys, over a station-mark at the surface, as at *k*, by setting the instrument level, placing the telescope to look vertically, and then, by a stage with a horizontal motion, bringing the center of the cross spider-lines to coincide with the station. Nothing is mentioned about sighting down a shaft; neither is the instrument adapted for that operation, because the hole in the vertical axis is too small, and the other necessary arrangements are wanting.

These instruments were unknown to the writer in 1870; moreover, they are of a distinct class, and not adapted for the general object which the writer then had, and still has, in view. For the particular use proposed, the perforated vertical axis of a portable and ordinary-sized transit-theodolite was his own invention, and new, at least in England.

2.—Among the greatest recognized disadvantages in the use of a transit-theodolite of the old style are the weight and the extra high standards, or Y's, required, when a telescope of sufficient length and power is applied to correspond to 6-in. circles, reading with verniers to either 10″ or 15″ of arc, and with a micrometrical eye-piece to one second of arc. For, in that case, such an instrument is much too high, heavy, and cumbrous; and it is also liable to vibration in windy weather, as likewise when too rapid or rough hand-pressure is applied to turn the telescope over vertically. In the general design of the new transit-theodolite under discussion, it was, therefore, decided that it should have comparatively low standards or Y's, and a long and powerful telescope, to suit the divisions of the circles and be capable of sighting to the bottom of the deepest shafts—conditions incompatible with the old English form of construction.

To carry this idea into effect, the horizontal axis-socket into which the telescope is, in ordinary cases, generally screwed in two parts, one on each side, was made larger and much longer than usual, and the middle part of the telescope-tube was also made in one piece, turned as nearly true as possible with respect to its optical axis, fitted into the aforementioned horizontal axis-socket or sleeve, and caused to slide a defined distance in it by turning the special milled head of a rack-and-pinion screw.

FIG. 1.



Dennert's and Pape's Theodolite.

When, therefore, a sight is required, as in Figs. 2 and 3, to be taken through the telescope and the center of the instrument down a vertical shaft, the telescope is slid through the axis-socket, or hub, until the object-glass end in revolving will clear the cross spirit-level tube fixed upon the vernier-circle. The focusing for clear vision of an object is then made in the usual way. On the other hand, when the object to be observed has great elevation, or, as the case may sometimes require, be in the zenith, the telescope is slid through the axis-socket, or sleeve, in the opposite direction, or until the eye-end of the telescope, carrying the micrometer-box and circle and the long diagonal eye-piece, will, as in Fig. 4, pass the vernier-circle. A clear view of terrestrial or celestial objects can then be obtained on turning the ordinary focusing-screw.

When the instrument is employed in land-surveying, tunneling, and railway and other works, where the elevation of objects on the surface is not great, the telescope is slid through the axis-socket, or hub, to its normal or middle position, and held firmly by its own rack-and-pinion screw, as shown in Figs. 5, 6 and 7.

The perforated vertical internal axis, previously described, and the sliding telescope, are the principal improvements introduced in the construction of this new transit-theodolite; and they are considered to be advantages not presented by the old-type surveying-instruments generally employed in England. If custom, prejudice and the personal interest of instrument-makers and users could be laid aside for more modern and progressive ideas, with a desire to search for and adopt the best, then it would be possible that improvements indicated by the writer, as also by others, might be utilized with considerable advantage. But, although there are persons possessing advanced scientific and practical ideas, and always ready to welcome improvements and inventions, still a great many instrument-makers believe in nothing except their own plans; and these they impress upon the minds of their purchasers. This is the principal reason why the old-model instruments have been adhered to for such a long time with rigid tenacity. From the description given, it must be evident that the transit-theodolite under notice is not only ad-

mirably adapted for all branches of surveying, but particularly so for connecting underground headings or tunnels leading from a shaft into a mine, or to the surface, and *vice versa.* In future, therefore, progressive engineers and mine-surveyors will have extra means at their disposal, enabling them to carry out this important operation with the greatest confidence, facility and precision, without having to depend, as at present is the case in Europe, upon one or two persons who possess an astronomical transit-instrument, or to employ instruments with auxiliary telescopes, which is the universal practice in North America.

Details of Construction.

Fig. 2 is a front view of the instrument, with the vertical circle, the end of the spirit-level attached to the verniers, the reading microscopes and the clamp-and-tangent screws seen to the right. The telescope has its object-glass at the lower end so as to sight vertically downwards. The micrometer, short diagonal eye-piece and milled head of the focusing-screw are seen at the upper end. The long and more sensitive spirit-level, shown to the left, is attached to the telescope and moves with it. The long-trough magnetic compass is temporarily mounted on the top of the telescope, and the lantern for illuminating the spider-lines is to the left. The standards, or Y's, rest upon the vernier-circle, and the reading microscopes and prisms for reading and illuminating the vernier and divided horizontal circle are seen to the right and left. The top of the vertical hole through the internal vertical axis is clearly visible at the center of the vernier-circle. The whole instrument is mounted upon a strong triangular leveling-base, and is leveled by three large milled-headed screws.

Fig. 3 is a sectional elevation of the instrument in the same position as in Fig. 2. The line AB passes through the optical axis of the telescope, the vertical axis of the horizontal divided circle, and in a vertical direction to the bottom of the shaft, or to the center of a station over which the instrument is required to be centered. The vertical circle, clamp-and-tangent apparatus, verniers and spirit-level attached to them are seen to the right in the diagram; and the long sensitive spirit-level *bb* is seen to the left, and is attached to the side of the telescope, but rises a little above its general level in order to give a clear

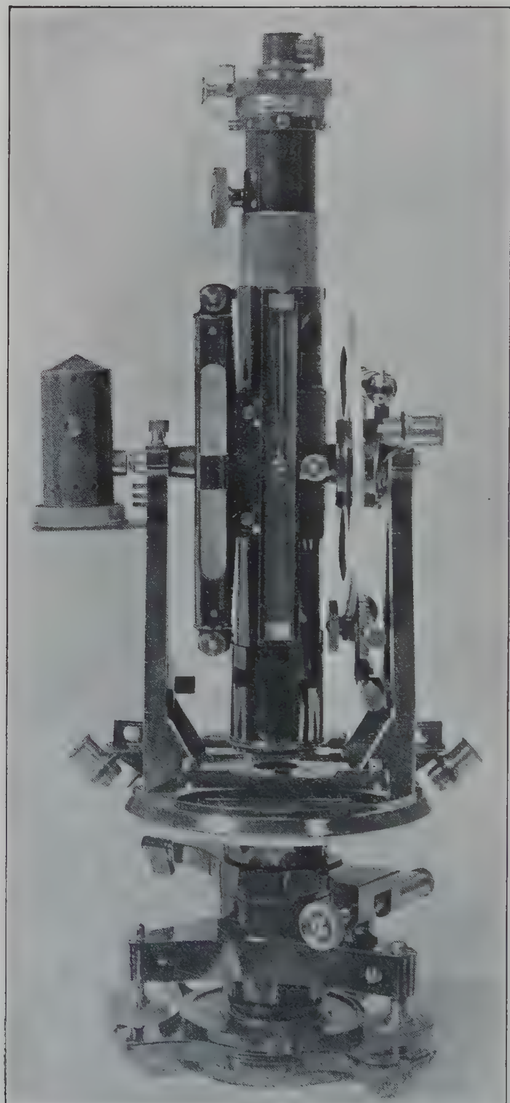
view. Two prismatic reflectors, having a horizontal motion, are represented at *aa'*, and illuminate the verniers and that part of the horizontal divided circle which may be seen through the two adjoining microscopes. The short diagonal eye-piece which is used when the telescope is looking in a vertical direction is seen at *c*, with its external screw, to which part a longer tube is attached when the telescope is reversed and a sight is taken to the zenith. The micrometrical divided circle, or head, is shown at *d*. This circle is attached to a screw which passes through the outside of the micrometer-box, to a movable frame fixed in the focus of the telescope. By moving the circle *d*, motion is given to the screw and to the internal frame carrying a vertical spider-line, which is thereby made to pass over the notches or divisions of a comb, also placed in the focus of the telescope. Each notch or division of the comb represents one minute; and when the head, or circle, at *d* is divided into 60 equal parts, each revolution represents one minute, and each division on the circle one second of arc.

Fig. 4 is a view of the instrument similar to Fig. 2, but taken on the opposite side; the vertical circle, the long, sensitive spirit-level and the lantern are seen on the reverse side. The telescope in this case points towards the zenith, and for use in this position has a long, diagonal eye-piece attached to it, instead of the shorter one of Fig. 2. When so placed, the instrument offers every facility for observing stars on opposite sides of the meridian, and close to it, for determining the latitude by the excellent and now well-recognized method of Talcotte. In this position, the arrangement of the clamp-and-tangent screws with respect to the horizontal circles and body of the instrument are more clearly seen.

Fig. 5 is a side view of the instrument, with the telescope reversed, showing the general arrangement of the telescope, with a portion of its long, sensitive spirit-level, the vertical circle, verniers and their attached spirit-level. The short, blank sights on the top of the telescope are prominent to the eye. The standards, or Y's, are elegant; and the particular form given to them appears to diminish their height. This position of the instrument shows clearly all the parts previously noted.

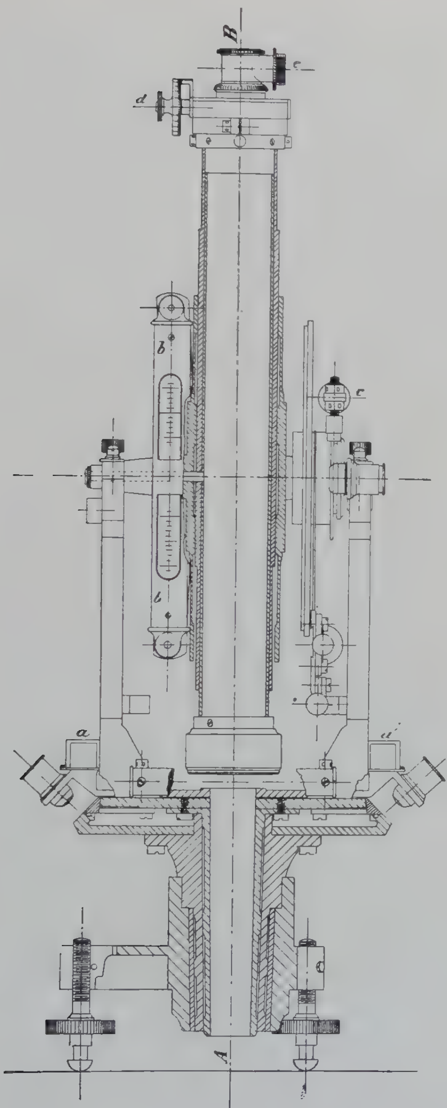
Fig. 6 is also a side view of the instrument taken on the side

FIG. 2.



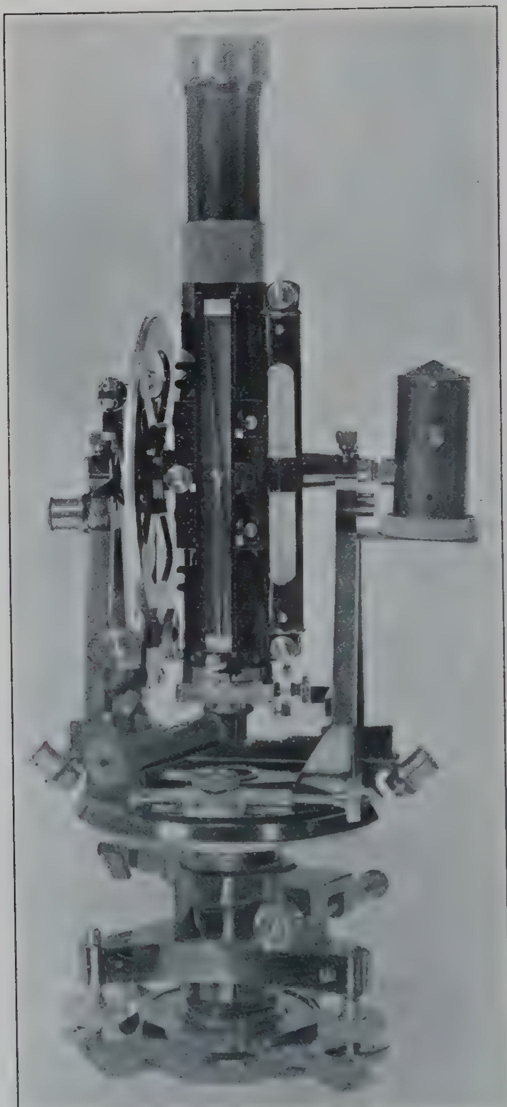
Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Sighting Downwards.

Fig. 3.



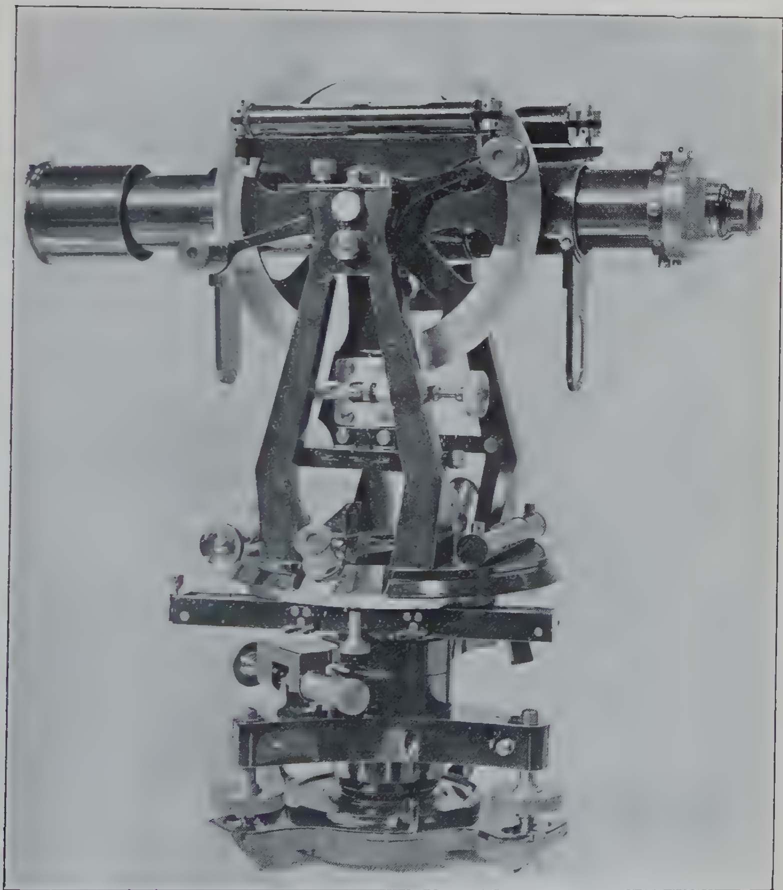
Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Sectional Elevation. Telescope Looking Vertically Down.

FIG. 4.



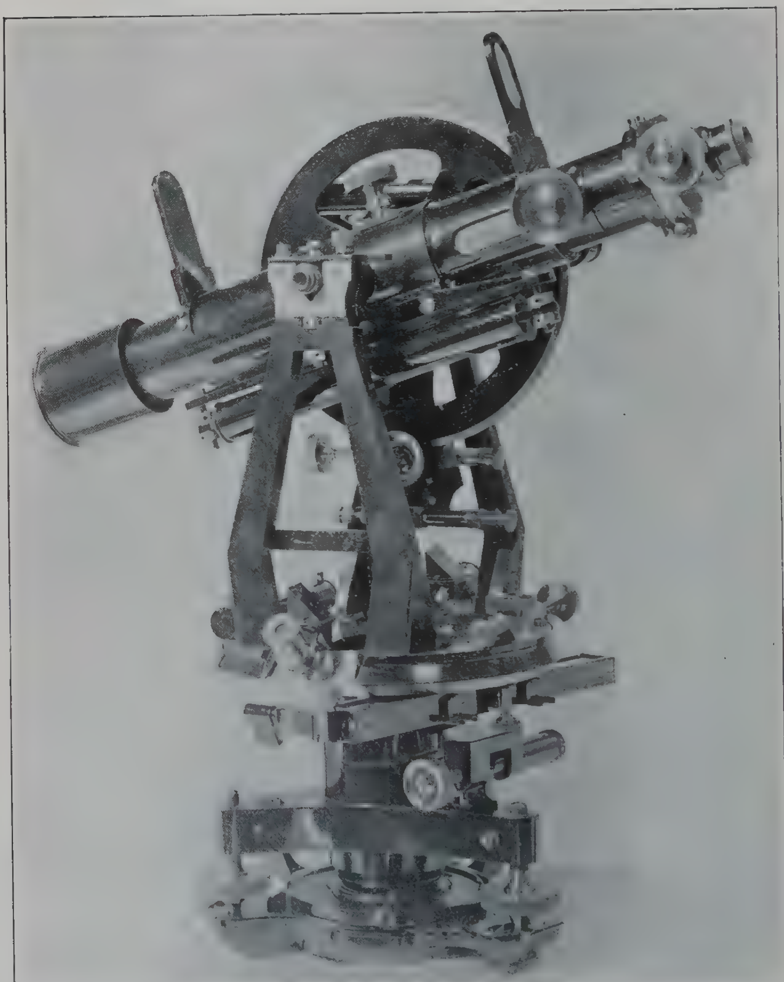
Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Sighting Upwards.

FIG. 5.



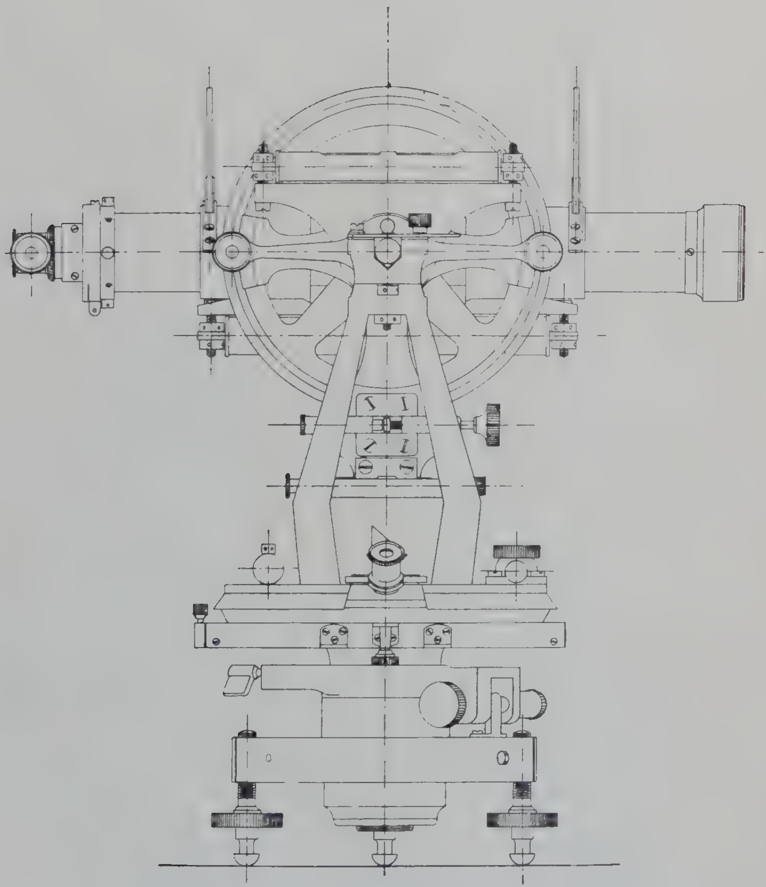
Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Side View, Telescope Inverted.

Fig. 6.



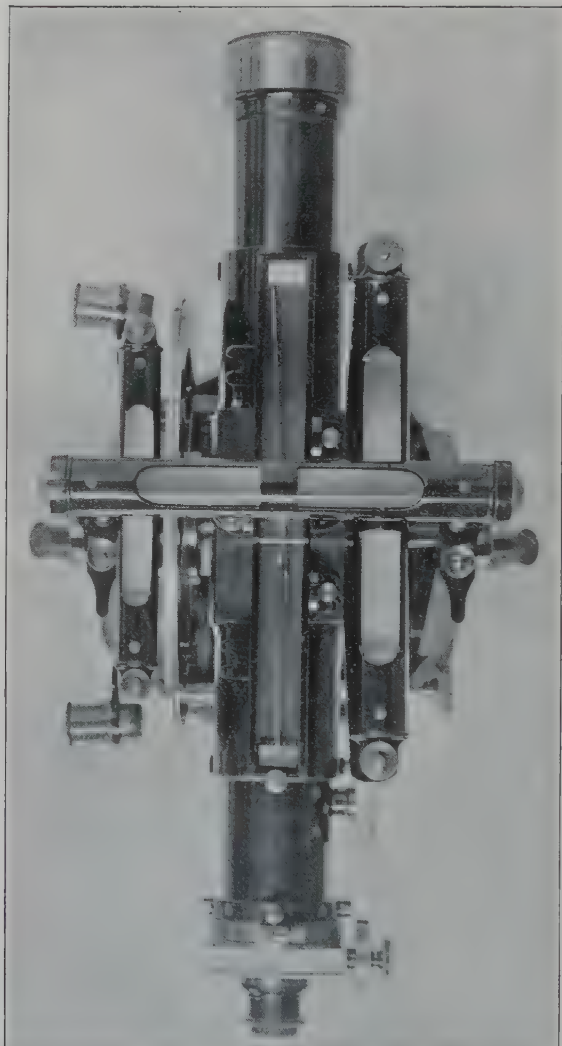
Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Side View, Telescope Right Side Up.

Fig. 7.



Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Side Elevation.

FIG. 8.



Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Seen from Above.

opposite to that shown in Fig. 5, and exhibits some of the parts reversed, and the telescope depressed.

Fig. 7 is a diagrammatic elevation of the instrument about one-third full size, exhibiting, as in Fig. 5, the front view of the vertical circle, its vernier-arms, verniers and spirit-level attached, also the short diagonal eye-piece at the eye-end of the telescope. The vertical circle is of the ordinary type, and has the same diameter as the horizontal one. On the opposite side of the telescope, and below its level in the diagram, is seen part of another longer and more sensitive spirit-level which, when the telescope is reversed (as in Fig. 5), appears above its general level. Independent of all the other parts of the instrument, this level forms with the telescope a very effective spirit-level, and, apart from the theodolite-principle, may be used in place of a special instrument for leveling operations. The short plain sights attached to the upper part of the telescope are useful when lines occur underground that are too short for seeing clearly through the telescope. When not so required, they are detached.

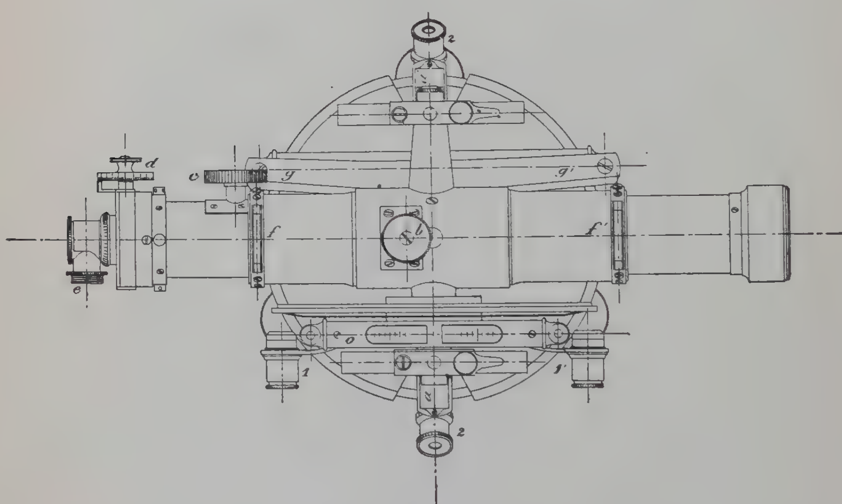
Fig. 8 is a view from above, looking down upon the instrument. The arrangement of the micrometer is shown at the eye-end of the telescope; the spirit-level to the vertical circle and the vertical circle are seen to the left; also the long and sensitive spirit-level to the right. The long-trough magnetic compass, mounted on the top of the telescope, and other parts, are clearly shown. The stride spirit- or axis-level appears above the other parts.

Fig. 9 is a diagrammatic general horizontal plan, looking down upon the instrument, in which *e* represents the short diagonal eye-piece, with the outward screw to which a longer tube may be attached, and *d* is the divided head of the micrometer, previously described in Fig. 3; *c* is the head of the focusing rack-and-pinion screw, and *b* is the head of the rack-and-pinion screw which gives motion to the telescope-tube, causing it to slide in the cylindrical part ff', which is screwed into the horizontal axis carrying the telescope; $a\,a'$ are the reflecting prisms attached to the verniers previously described; 2 2′ are the microscopes for reading the verniers and divisions on the horizontal circle; 1 1′ are the microscopes for reading the verniers and divisions on the vertical circle. The spirit-level

attached to the arms of the verniers of the vertical circle is represented at *o*. The base to which the more sensitive and longer spirit-level is screwed, on the opposite side of the telescope, is seen at $g\,g'$.

The diagram, Fig. 10, represents the triangular leveling-frame which is screwed to the top of the tripod-stand, and into the upper locking-plate of which the three leveling-screws of the theodolite are placed and locked when in use. At the center a large hole is made, through which the telescope looks, and a clear view is obtained in a vertical direction downwards. The

FIG. 9.



Hoskold's Mining and Civil Engineer's Transit-Theodolite.
Diagram, View from Above.

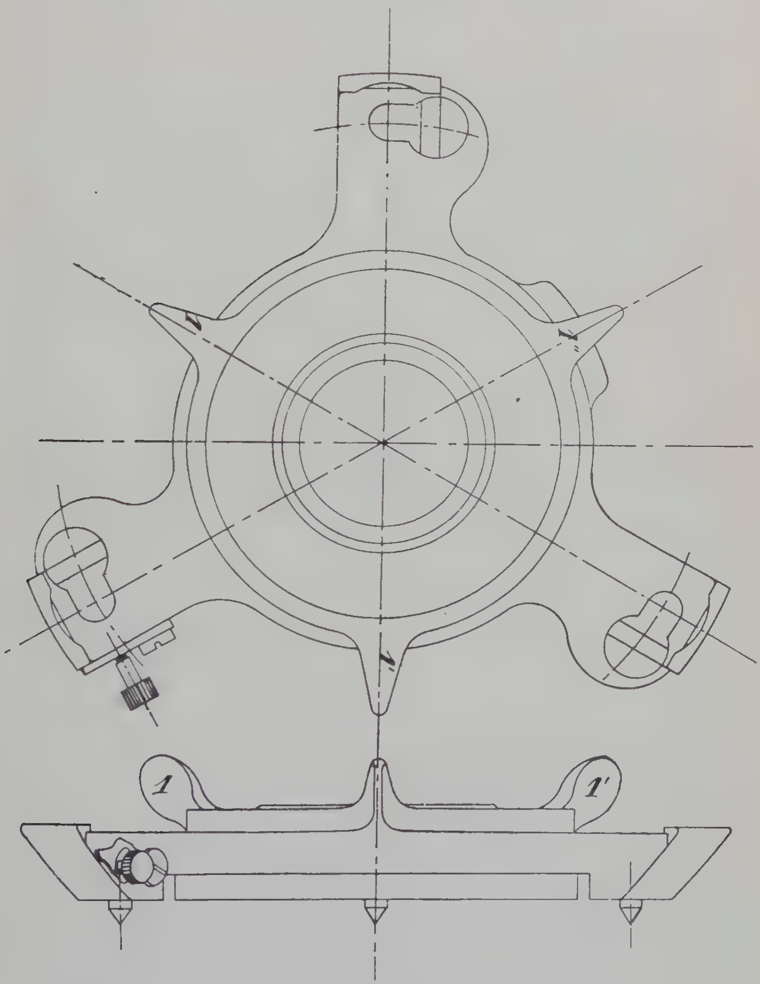
upper plate shown has three small projections upwards, 1, 1′, 1″, to which the fingers are applied with pressure for clamping the whole together, including, of course, the theodolite.

Fig. 11 is a sectional elevation of Fig. 10, showing the form of the fixing- or clamping-plate 1 1′ more clearly. At the bottom of the triangular leveling-plate, three conical pointed short projections are shown. They are steel points screwed into the triangular plate at the angles of an equilateral triangle, and may be used with the theodolite upon a stone pillar, or wall, or in some low position, without using the tripod-stand.

Fig. 12 represents the trough magnetic compass, the needle

of which has very small points; and by the use of a hand-lens the coincidence of the needle-points with the zero of the arcs may be observed with greater exactitude. It will be seen in

Figs. 10 and 11.



Plan of Locking-Frame.
Cross-Section of Locking-Frame.

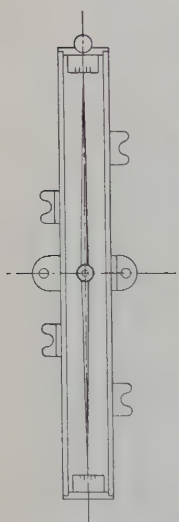
Figs. 2, 4 and 8 that the long-trough magnetic compass is mounted on the top of the telescope; but there is a groove, specially made, under the horizontal divided circle, so that an observer may place the magnetic compass in either of these

positions, to suit convenience or clearness of vision. The diameter of the horizontal circle is 6 in., divided upon silver to 15 min., with verniers subdivided to read to 15 sec. of arc; and, by means of the micrometrical eye-piece attached to the telescope, angles may be measured to 1 second of arc, and by estimation to less.

Traversing-Stand.

When using the new instrument to connect the first line in an underground survey to the surface by direct telescopic sight down a vertical shaft, a specially constructed tripod-stand, invented by the writer, is employed. Its legs at the upper part are mounted with a traversing-apparatus, *i.e.*, a table, upon which the transit-theodolite is locked ready for use. The table, or head, of the stand, Fig. 13, consists of a metal plate of sufficient thickness, the irregular periphery of which is contained within a circle 10 in. in diameter. Apart from the irregular projections of the plate, its body would be contained within a circle of $7\frac{1}{10}$ in. in diameter. The legs of the stand are screwed to the metal projections marked 8 8 8 8 8 8. Parallel to the line AB, an opening $6\frac{1}{2}$ in. in length and $1\frac{1}{2}$ in. in width is made in the plate. Two other center lines are also shown at *ab* and *cd*, and on each of these a long slit is cut in the plate $7\frac{4}{10}$ in. long and $\frac{5}{10}$ in. wide. These elongated slits are marked 10 10′ and 11 11′.

Fig. 12.



Compass.

The upper- or carrying-plate *i i′ i″ i‴* is placed upon the table just described, and is intended to travel from the center line CD both ways, or towards A and B, as far as the other conditions of the construction will permit. A triangular locking-plate, similar to Fig. 10, without the circular clamp 1 1′ 1″, is screwed upon the central hollow male screw *o*, and the theodolite is fixed in the triangular locking-plate, not shown; and, consequently, any motion communicated to the carrying-plate *i i′ i″ i‴* would move the theodolite with it. The large clamp-screws *m m′*, each with a stout pin passing from the under side of the metal table through the slits 10 10′ or 11 11′, are

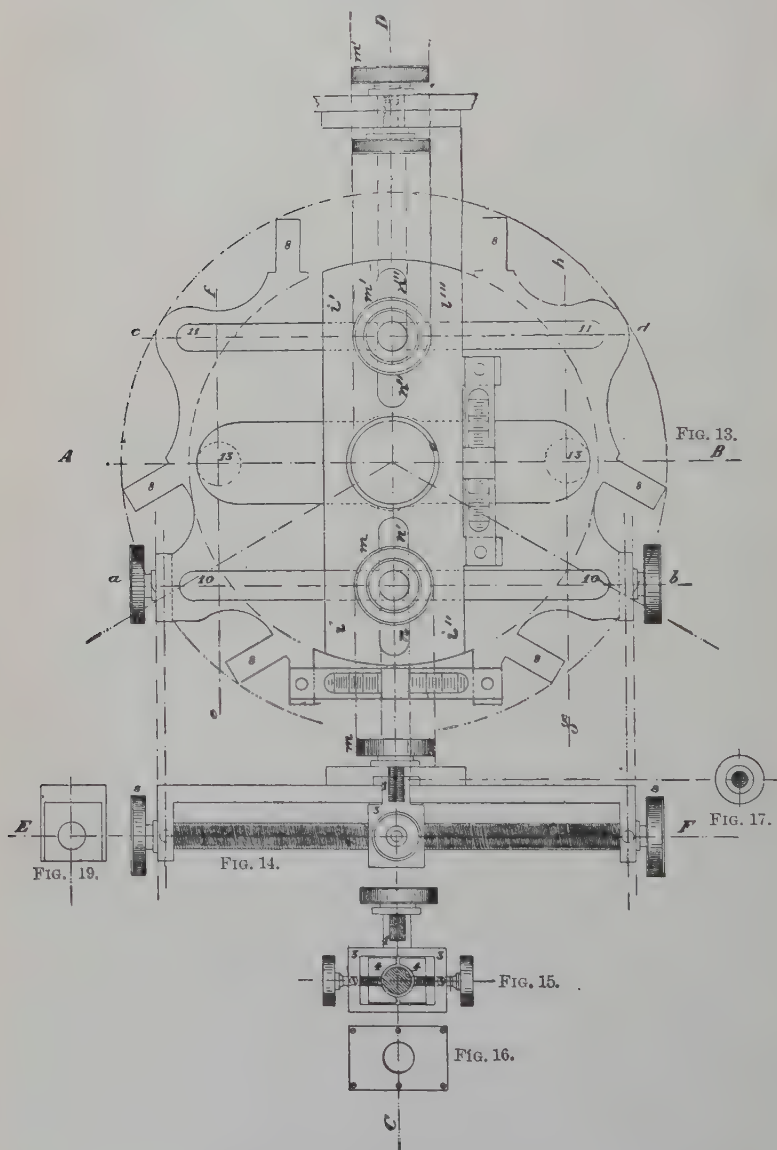
clamped each against a recess cut in the under side of the carrying-plate by a collar, Fig. 17, which is screwed upon the upper neck of the pin. When the two clamp-screw heads m and m' are slackened, the pins keep the carrier-plate in its place, while it traverses upon the table the entire limits allowed by the slits 10 10′ and 11 11′, along which the pins slide. The mode of clamping the carrying- or traversing-plate to the table-plate is clearly seen in Fig. 14, which is a section taken along the line ab of Fig. 13. The heads $s\ s'$ of the long tangent-screw, or slow-motion screw, upon the center line $E\ F$ are those at a and b of Fig. 13. The screw-heads $s\ s'$ have square shoulders, which press against two downward-hanging metal projections forming part of the head or stand; so that, when the screw-heads are revolved, the screw remains in the same normal place.

Fig. 15 is a cross-section of the metal box 3 of Fig. 14, and of the pin which slides in the slit 10 10′, with its proper clamping-screw, marked m in Fig. 13. This box holds within it the two divided halves of a rectangular piece of metal which has a female screw cut lengthwise of the central dividing-plane, to fit the surface of the long tangent-screw, or slow-motion screw, of the central line $E\ F$. Through each end of the box a horizontal screw passes into one end (4) of the halved rectangular piece of metal, in such a way that when turned they do not advance, but separate or bring together the two halves of the rectangular piece of metal, or make them clasp the long slow-motion screw. When the two halves of the rectangular piece of metal are thereby separated, the clasping effect upon the long tangent-screw is nullified, and the carrying-plate, with the theodolite locked upon it, may be pushed unhindered along the table-plate until, say, the vertical hair of the telescope comes within the field of two illuminated objects placed at the bottom of a shaft below the instrument. When this has been done, the clamp-screw m is made to clamp together the carrying-plate and the upper part of Fig. 15; and, by turning the two horizontal screws of Fig. 15, the two halves of the elongated plate 4 4′ are made to clasp the long tangent-screw, or slow-motion screw, bringing it into action. Then the heads $s\ s'$ are turned, and the vertical spider-line of the theodolite is made to bisect the two illuminated marks at the bottom of the shaft. When this has been effected the screw m', Fig. 13, which is shown

in the section Fig. 18, is turned, clamping the plates together; so that if an attempt were made to move the screw-heads $s\,s'$, no

FIGS. 13–19.

FIG. 18.



Hoskold's Traversing Stand.

effect would be produced upon the vertical spider-line in the telescope. But such an act might spoil the threads of the screw.

Fig. 19 simply represents the inside of the metal projection with a bracket, against the exterior part of which the shoulders of the screw-head s or s' press. The brackets resist the pressure of the screw-heads. Fig. 16 is the cover for the metallic box of Fig. 15, and, when placed in position, ensures a smooth motion to the clasping halves of the rectangular piece of metal inside.

The long slow-motion or tangent-screw $E\ F$ appears, on the whole, to be the only mode of securing the maximum traversing-distance of the carrying-plate upon a table of comparatively moderate diameter. It is true and evident that an ordinary clamp-and-tangent screw might be applied; but, in that case, a portion of the space in the slit 10 10′ would be occupied with a pin and the appendages of the clamp-screw, leaving less space for the travel of the carrying-plate, and proving injurious to the general construction; but of this we will speak further on, when describing the mode of planting the instrument over the top of a shaft.

It will be observed that two other shorter slits are cut in the table, nn' and $n''n'''$, at right angles to the lines ab and cd, so as to give a lateral motion to the carrying-plate and theodolite when it is required to center the instrument over common surveying-stations. Two spirit-levels are also mounted upon the table, so that the tripod-stand may be placed approximately level over the top of a shaft before the theodolite is placed upon it.

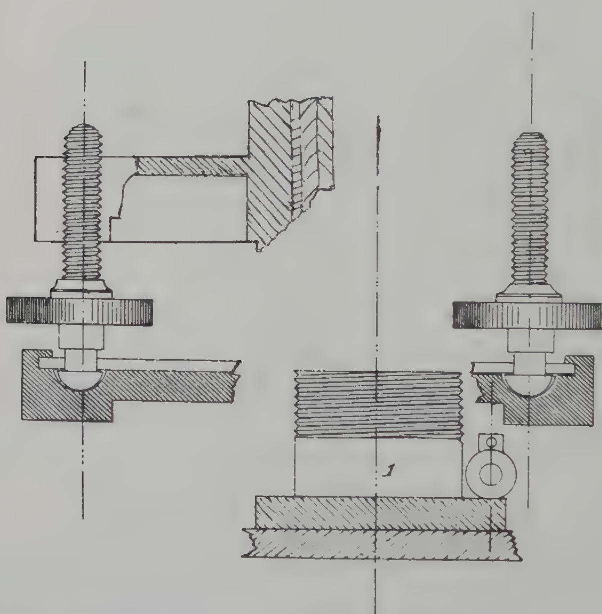
Fig. 20 is an enlarged sectional elevation of the central portion of the table and carrier-plate, taken along the line CD, and represents the hollow cylindrical part o, with the male screw cut on the outside top part of it, above 1; and also a portion of the locking triangular frame and two of the theodolite leveling-screws, with a portion of the triangular leveling-frame attached. The space marked 1 on the sectional elevation, between the carrying-plate and the screw portion above, is intended to give room for the fingers when manipulating the large heads of the screws m and m' of Fig. 13.

To Connect Underground Workings with the Surface.

The mode of proceeding in connecting the first line in an underground heading or tunnel leading from a shaft into a

mine is as follows: A downcast shaft, Fig. 21, is selected (work being suspended in it), and at a convenient distance from the bottom of the shaft, along the main road, A, or at the first bend of it, a permanent station is formed by driving a steel or copper peg, $1\frac{1}{4}$ in. in diameter and 12 in. long, into the floor of the mine at the point selected; but if the floor consists of hard rock, a hole is drilled and the metal peg is firmly inserted. A corresponding hole is also made in the roof of the heading,

Fig. 20.



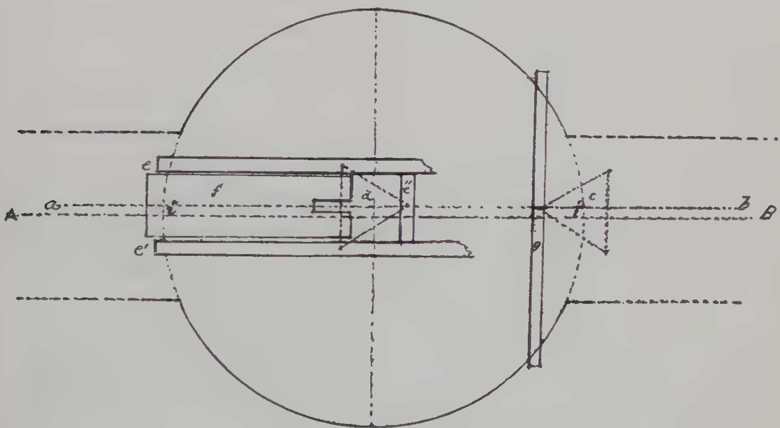
Sectional Elevation of Central Portion of Table and Carrier-Plate, and of Portions of the Locking-Frame.

vertically over the metal peg or station, and another metal peg with a hole in its lower part is driven into the roof and properly adjusted; so that, when a plumb-bob line is suspended, the fine point of the bob coincides with a counter-sunk hole made in the center of the metal peg or station.

It would be convenient to have two stout wooden benches, 4 ft. in length, 14 in. in width, and 2 in. in thickness, with four legs each, and with strong steel short spikes in all of the legs. One of the benches may have a height of 20 in., and the other

such a height as would, with an illuminated box to be placed upon it, amount to $19\frac{3}{4}$ in., or other convenient height. The higher of these benches should be placed with the inner edge of one of the longest sides to coincide with a vertical line which would fall upon the center of the metal peg, or station, in the floor of the heading *A*. The lower bench is placed at *i*, in the center of the heading, with one of its edges coinciding with a vertical line from the inner wall of the shaft. It is presumed that the two places where the benches are placed are level. A point, *i′*, is then selected in the outer, or opposite, wall and middle of the shaft, and a strong steel wedge or nail,

Fig. 21.



Plan. Setting the Instrument Over a Shaft, in Transferring an Underground Line to the Surface.

with a hole in the outer end, is driven or inserted into the wall of the shaft. A flexible copper wire, the diameter of which must be determined, is attached by one end to the eyehole of the steel wedge, and stretched over the benches and along the heading; to the other end of the wire a sufficiently heavy plumb-bob, with a fine point, is fastened. That part of the wire falling from the edge of the bench to the metal peg or station is of sufficient length to cause the plumb-bob to be freely suspended, and the fine point of the bob is brought to coincide with the fine hole sunk in the center of the peg. The coincidence is effected by moving the copper wire transversely along the edge of the bench. When this has

been done, the direction of the wire represents the future permanent reference base-line as indicated, at one end, by the metal station in the floor and roof of the heading, and at the other end by the steel wedge inserted in the side of the shaft. This base-line is the one which it is required to reproduce at the surface in the same direction, and to which all underground and surface surveys must be referred.

Two small wooden boxes are prepared, according to the plan adopted by Prof. Liveing,* each provided with a strong electric light placed in the side of the boxes, and with a reflector, placed at an angle of 45°, at the opposite side. Finally, each box is covered with a ground-glass lid for diffusing the light and illuminating a cross made upon each lid. One of these boxes must be placed as near to one of the sides of the shaft as is possible, and upon the lower bench previously described; and the other box is supported in a similar manner on the opposite side of the shaft, just under the strained copper wire. The longitudinal line of the cross upon each box is made to coincide with the copper wire. Two points, at least, would then be illuminated at the bottom of the shaft, forming as long a base-line as is possible for this object. It will be observed that the copper wire may be about $\frac{1}{4}$ of an in. above the illuminated lids of the boxes. In this way the longitudinal line of the crosses and the copper wire would appear as a single line, when viewed through the telescope of the transit-theodolite from the top of the shaft. If, however, the great depth of the shaft renders it impossible to view such a line, then stronger electric lamps of another class must be employed; and on this point the advice given by Prof. Liveing in his paper (before referred to) may be followed with great advantage.

When this special arrangement has been made at the bottom of the shaft, a previously constructed wooden frame, consisting of two stout balks of timber joined together with a third ($e\,e'\,e''$), or a cross-piece of the same dimensions, is placed over the top of the shaft upon a good foundation and leveled, in such a manner that a central line, passing midway between the balks, shall coincide as nearly as is possible with a line passing through the center of the shaft. The steel-pointed

* *Trans. N. E. Inst. M. E.*, vol. xviii., Part I., pp. 65–71 (1869).

foot of one of the legs of the tripod-stand of the theodolite is fixed upon the left-hand balk, that of a second upon the right-hand balk, and that of the third upon the cross- or brace-balk, in such a manner that the theodolite may be over the center of the shaft. The opening between the two longitudinal balks on the observer's side is fitted with a strong wooden platform, f, made of stout boards, reaching nearly to the middle of the shaft; and upon it the observer stands during the observations. The platform must not be joined to the balks, lest any possible vibration might be communicated to the instrument. If it were possible to ascertain or determine the center line of the shaft at the surface to be precisely, with perfect correspondence, in the same vertical plane as the underground line AB, then the frame $e\ e'\ e''$ could soon be placed in a proper position, and the vertical sighting to follow would be simplified; but it sometimes happens that there are obstacles preventing a determination of the true center of the shaft by ordinary measuring at the surface, corresponding to that previously set out at the bottom, and then a difference may exist more or less great, such as is indicated by the line ab, which in this case becomes the center line of the wooden frame $e\ e'\ e''$. For such a difference, or a greater one, the traversing-stand previously described has been invented.

When the legs of the traversing-stand have been placed upon the frame, and the steel points of the legs made to occupy the three points formed by the imaginary equilateral triangle d, the spirit-levels attached to the table of the traversing-stand will show whether the side-timbers of the frame have been placed in a level position or not. When these levels have been satisfied, the transit-theodolite is placed upon the traveling-frame already screwed to the carrying-plate, and is firmly locked in that position. The instrument is then accurately leveled, the zeros of the horizontal divided circle and verniers being made to coincide. The telescope is then turned down, to occupy the position shown in Fig. 2 and in the sectional elevation Fig. 3, and when focused for clear vision, the bottom of the shaft is examined through it. If the illuminated marks placed there appear in the field of view, the clamp-screw m, Fig. 13, is clamped; also the side-screws attached to the box, Fig. 15. Then the screw-heads s, s', Fig. 14, are turned, giving a slow

lateral motion to the carrying-plate and theodolite; and by this means the vertical spider-line in the focus of the telescope is made to coincide with the two illuminated marks previously placed at the bottom of the shaft. If, after the vertical spider-line is made to bisect the first illuminated mark, it should pass on one side of the second, the theodolite must be moved a little in azimuth by turning its body tangent-screw, and the process of bisecting the first and second illuminated marks repeated. A few such trials may be required before the vertical spider-line will pass through the center of the two illuminated marks indicating the direction of the line AB below ground.

The telescope must now be raised to a horizontal position, taking care not to disturb the instrument otherwise. An examination of the spirit-levels will indicate any deviation. When all is satisfactory, the line AB is set out on the surface; for its direction will be indicated by the vertical spider-line in the focus of the telescope. With proper care, and with an instrument in good condition and adjustment, this operation may be performed within a few seconds of the truth. Considering that a single operation, or at most two such operations, one proving the other, may be sufficient during the life of a mine, the line should be set out on the surface in a permanent manner, say by placing stone pillars in the ground, with the center-line marked by a copper plug in the center of each block. The line thus set out becomes a base-line for all surface-surveys; and, as it also exists underground, it would be employed for the same purpose in underground-surveys. This line is, therefore, of great value as a future base-line of reference, and exceedingly useful when it may be required to sink a shaft at a point on the surface to strike a given point below ground; as also for insuring that all surface objects and boundary-lines are placed in their true position in reference to all underground-workings. It sometimes happens, in the older mining-districts of Europe, that shafts are surrounded by buildings which may impede the direct setting out of the base-line which we have described; and, in that case, an opening must be found, in order to set out another line at a defined angle with the underground base-line, and that angle can be allowed for when plotting surface-surveys.

It may happen in some cases that a single piece of timber

may be employed to support one of the legs of the theodolite, the other two resting upon a raised and level part of the surface, as represented in the dotted triangle *c*; but, in general, the writer is of opinion that the first plan described is preferable. In either case the angle subtended by a 20-ft. diameter shaft at a depth of 500 yards would not be more than 46′ 1″.

The size of the copper wire to be placed in the bottom of the shaft may be determined by experiment. At a distance upon the surface equal to the depth of the shaft, pieces of copper-wire 7 or 8 ft. long, of various diameters, should be suspended in front of a sheet of glass illuminated from behind by an electric light. The vertical spider-line in the focus of the telescope of the theodolite should then be directed to the copper-wires in succession, and it would be instantly determined which size is suitable to be employed for the underground base-line. It would be better to use a stronger electric light at the bottom of the shaft than the one used at the surface.

It may happen that for some reason or other the center-line *ab* of the wooden frame may not coincide with the line *AB* below ground within two or three inches, or probably more. In such a case, the traversing-stand, Fig. 13, would prove of great advantage and offer great facility in manipulation; for the carrying-plate mounted on the table of the stand moves the theodolite a distance of 3 in., or more, each way from the center line. The writer considers that, without some such traversing-stand, it would be uncertain how many trials would be required, and how much time would be lost, in using an ordinary tripod-stand, before exact coincidence could be made between the spider-line in the focus of the telescope and the illuminated reference-marks placed below ground.

The metal table upon which the traversing-apparatus moves may, at pleasure, be detached from the tripod legs; and, as there are three strong steel points, about 2½ in. long, screwed into the under side of the metal table, equidistant one from the other, it may be placed upon a low three-legged stool. The transit-theodolite may then be used for a similar operation underground; or the apparatus may be placed upon a stone pillar or wall on the surface.

When railway-tunnels have to be constructed for great distances, shafts are sunk from the surface at intervals along the

direction of the tunnel, and, to shorten the time of construction, portions of the tunnel are driven simultaneously from the bottom of the shafts in each direction. Consequently, the determination of the direction the tunnel should take underground is the reverse operation of that which we have described. The transit-theodolite is set over each shaft and in the surface-line of the tunnel. The telescope is then turned down to sight in a vertical direction, and two marks are placed in the bottom of each shaft to coincide with the vertical spider-line in the focus of the telescope. Portions of the tunnel are then driven in the direction indicated by the marks, and, after they have been driven a short distance, the operation of sighting vertically is again effected, and the direction below ground is checked.

One of the most accurate plans for the purpose was adopted for determining the direction of the Severn Tunnel, England, the total length of which amounted to nearly 8000 yards. An account of the work has been published by Mr. Richardson, the engineer,* showing the nature of the undertaking and the difficulties of the construction. At the bottom of the shaft a wire was stretched horizontally from one side of the shaft 100 yards along the trial-heading, giving a length of about 14 ft., at the bottom of the shaft, visible from the top, and lighted by an electric light. The wire at each end passed over the threads of a horizontal screw, and weights upon the ends kept the wire taut. By turning the screw at the apparatus, the wire was brought into the center-line under the telescope; then, by turning the screw at the far end, the wire was brought to coincide with the direction of the vertical cross-hair of the telescope, indicating the direction of the tunnel. According to the published account, a base-line of 100 yards, thus extended upon a line of 14 ft., was practically free from error; "and the result has fully justified the method adopted, the error in the meeting of the two headings being practically *nil.*"

SECRETARY'S NOTE.—By reason of the uncertainty and delay involved in postal communication with Buenos Aires, it has been necessary to print the foregoing paper without the final

* *British Association*, vol. for 1875 (in which the paper is given by title only). See, also, *Engineering*, vol. xxxiii., pp. 47–49, Jan. 20, 1882.

and conclusive (though not without a partial) revision by the author. Any important changes therein which may be thereafter desired by him will be sent to members in separate form, and also included in Vol. xxxii., which is to appear this year. —R. W. R.

The Litharge Process of Assaying Copper-Bearing Ores and Products, and The Method of Calculating Charges.

BY WALTER G. PERKINS, GRAND FORKS, BRITISH COLUMBIA.

(Mexican Meeting, November, 1901.)

In the assay of copper-bearing material for gold and silver, the elimination of copper before the final cupellation is of course essential, because any copper left in the lead-button will carry gold into the cupel; and a method which will effectively remove the copper with the smallest amount of manipulation is desirable. The scorification method is often rendered long and tedious by the necessity of repeatedly re-scorifying the button—to say nothing of the risk of losing Au–Ag thereby incurred. An ore carrying, for instance, 10 per cent. of copper and only 0.1 or 0.2 oz. gold per ton, cannot be scorified with accurate results, because so many portions would have to be taken in order to get enough gold for weighing. On the other hand, the crucible method, with potassic nitrate and nails, would not do at all in such a case, because all the copper would be reduced by the nails, and (if the charge were 0.5 A. T.) this would defeat cupellation, by causing cupel-absorption of gold.

In matte-assays, more concentrated value permits the determination of gold from smaller portions, and thus diminishes the difficulty experienced with ores.

The method here described has been severely tested, during use for more than a year, and has never failed hitherto, in the assay of any ore or product to which it has been applied.

It is not proposed as perfect for every variety of ore or matte—probably no method would be that; but it is believed that, intelligently used, with the modifications dictated by practice, it will give better results, with less expenditure of time and labor, than any other known to the writer.

This method is based on the fact that PbO can be so used in a crucible, together with subsidiary fluxes, such as Na_2CO_3, K_2CO_3, SiO_2, KNO_3, and flour, as to give, in the determination of gold and silver, ultimate results at least equal, and in most cases superior, in accuracy to those of scorification. If the analysis of the ore be approximately known, the charge can be so calculated as to give for all ores and mattes a uniform slag, and a clean lead-button, containing only small quantities of copper or other interfering elements, thus doing away with the tedious operations and repeated manipulations of the scorification-method.

According to experiments in control-assays of ores and mattes, the slag that gives the best results is one of which the section, shown by breaking the cone after cooling, exhibits a silicate of lead, copper and iron on the outside edge, gradually passing to crystalline litharge towards the center. At the proper temperature this slag pours very fluid, without including small shots of lead, and gives a clean, bright button, with little or no slag adhering to it.

The temperature of the furnace must be carefully regulated, if the calculated flux is to do its work properly. There is danger in both directions, above and below the proper point. If the furnace be too cold, the slag will be wholly crystalline and will not pour well; and probably some small shots of lead, not collected with the button, will remain in the crucible. On the other hand, if the furnace be too hot, the charge will take up silica from the crucible, leaving in it cavities in which lead may be deposited, and overlooked. Excessive temperature, moreover, increases loss by volatilization.

The best results have been secured by starting with the muffle fairly red, and a rising fire, which should in 30 minutes increase the color of the muffle to bright-red, with the charge all reduced and fusing quietly. The furnace is held at this heat for 10 minutes, and then the charge is poured. The danger of boiling over is eliminated by the fact that the bulk of the charge is lead oxide, without excess of silica or potassic nitrate to bring about any violent action. Such action is invariably encountered in using the nails or nitrate method, where the fluxes are not well balanced, and everything is added or left out, on the cut-and-try-again principle.

Calculations of Charges.

In order to calculate the proportion of ore and flux, the analysis of the ore must be known as regards Cu, SiO_2, Fe and S. The reducing-effect of the sulphur and the oxidizing-effect of the nitrate must be known, not from theory, but from the results of practice with a variety of ores, such as a smelter receives, from which an average standard has been deduced. The following table was thus constructed from such experiments, made upon the same charges of ore as were used in the final assay. It was thus found as a practical rule that, upon a charge of 0.5 A. T. of ore:

1 gramme of flour will reduce	10	grammes	Pb	from	PbO
4 per cent. of sulphur will reduce . .	16	"	"	"	"
4 per cent. of antimony will reduce . .	3	"	"	"	"
4 per cent. of arsenic will reduce . . .	6	"	"	"	"
1 gramme of KNO_3 will oxidize . . .	4	"	"	to	"

The amount of PbO to be used will depend on the impurities to be fluxed off, the principal of these being copper, which must be taken out in order to reduce the loss by cupel-absorption. From low-grade ores (2 to 4 per cent. copper), 5 A. T. of PbO to 0.5 A. T. of ore, and from matte (48 to 60 per cent. copper), 8 A. T. of PbO to 0.1 A. T. of matte, will remove nearly all the copper.

To get a slag of the composition described, SiO_2 must be added, if necessary (after calculating the percentage of SiO_2 in the ore), to make up the ratio of 1 part SiO_2 to 16 parts PbO. The percentage of S should also be calculated, and oxidizing or reducing agents added, to obtain a button of the required weight, which should be about 16 grammes. The buttons will vary to the extent of a few grammes either way, by reason of difference in the temperature of the furnace; but with care and practice this difficulty can be largely avoided.

On ore containing, for example, 5.4 Cu, 29.4 SiO_2, 28.2 Fe, 13.1 CaO, and 15.8 S, the charge is calculated as follows. This ore contains a good deal of Cu, and also a high percentage of S, which would necessitate the use of a considerable amount of KNO_3. It is, therefore, advisable to take as a charge only 0.25 A. T. of ore, to which should be added 8 A. T. of PbO, 0.5 A. T. of Na_2CO_3, K_2CO_3, and 18.3 grammes of SiO_2. Since

4 per cent. of sulphur, as above stated, would reduce 16 grammes of lead from 0.5 A. T. of PbO, this charge, containing nearly 16 per cent. of sulphur, but being only half as large, would give a button of about 32 grammes. To obtain a button of 16 grammes, therefore, enough KNO_3 must be added to oxidize 16 grammes of Pb back to PbO. This amount will be, according to the figures given above, 4 grammes of KNO_3. The charge is to be thoroughly mixed and shaken down in the crucible, which is then filled up with NaCl. With careful melting, a button of about 16 grammes will be obtained.

Covers.

As regards the efficiency of different covers, it may be observed that, with the same ore and flux, and under circumstances otherwise the same, two crucible-assays of a high-grade gold-ore gave the following results: with salt as a cover, 20.16; with borax, 19.09; while by scorification, 19.90 ozs. per ton of gold were obtained.

This tends to show that there is less volatilization with salt than with borax. For all-round use, salt is certainly the safest cover. Moreover, when salt is used as cover, the buttons are more uniform, because the sulphur does not volatilize; whereas, borax gives buttons of variable size, because variations in the furnace temperature offset the sulphur directly, and may prevent it from exercising its full reducing-effect.

The Effect of Arsenic and Antimony.

Arsenic and antimony interfere with this method only when present in proportions exceeding 4 per cent., which is rarely the case in any other sulphide-ores than arsenopyrite or stibnite. The following experiments were made to determine the effect of these elements.

Experiment No. 1 comprised 4 crucible-meltings, each crucible containing 0.5 A. T. of the ore (a clean sulphide, containing 4 per cent. of S), to which, in the first crucible, no arsenic or antimony was added; in the second, 0.291 gramme (2 per cent. of the ore-charge) of antimony; in the third, the same amount of arsenic; and in the fourth, 0.291 gramme of each, making together 4 per cent. of the ore-charge.

The reducing-effect of Sb and As is seen in the following figures:

In	Crucible	No. 1,	the	button	was	16	grammes	Pb.
"	"	" 2,	"	"	"	17.5	"	"
"	"	" 3,	"	"	"	19.0	"	"
"	"	" 4,	"	"	"	20.0	"	"

Experiment No. 2 was made with ore containing SiO_2, 29.0; Fe, 29.55; S, 25.4; and Sb, 4 per cent. Two charges were run, side by side. Each consisted of 0.25 A. T. of ore; 0.5 A. T. of Na_2CO_3, K_2CO_3; 8 A. T. of PbO; and 18 grammes of SiO_2, to which, in the second charge, 8.7 grammes KNO_3 were added. Salt was used as cover in both.

The first charge gave an actual button of 49.5, the calculated button being 50.8 grammes. The second gave an actual button of 17.4, as against a calculated button of 16 grammes. Both buttons were soft and clean, and showed none of the characteristics of As or Sb.

Conclusion.

This method may not be universally applicable; but it is useful in a smelter, where the analysis of the ore to be assayed, or, at least, of the last lot thereof, can always be obtained on the premises. Under such circumstances it is, beyond comparison, better than the haphazard KNO_3-and-nails method. Moreover, in a smelter where there are always stock-ores, assay-fluxes can be mixed in large quantities and kept on hand. For matte, a single standard flux can always be used, since that product is, within 1 or 2 per cent., constant in composition.

DISCUSSIONS.

The Evolution of Mine-Surveying Instruments.

Concluding Discussion.*

BY DUNBAR D. SCOTT, HOUGHTON, MICH.

So many contributors have appeared recently with commendable arguments that I re-enter the field apologetically, taking the liberty first to supplement Mr. Davis's paper by showing how that clever mechanic, Mr. Berger, has converted the interchangeable auxiliary telescope into a solar of the Saegmuller type.†

The auxiliary is made to revolve about the polar axis and in the declination circle by means of a new appliance called the "equatorial adapter," which is shown attached in Fig. 164, and more in detail in Fig. 165.

It consists of two parallel circular plates, the lower one of which is screwed to the "vertical pillar" of the telescope. The upper carries the polar axis with its peculiar bearing-arm, to which the auxiliary is attached in a position similar to that which it occupies when at the side of the instrument. The polar axis may be adjusted to verticality by means of a permanently attached bubble-tube and two small thumb-screws, which operate against springs between the plates; and the bearing-arm is governed in its revolution about the polar axis by the usual small clamp-and-tangent-screw arrangement.

---

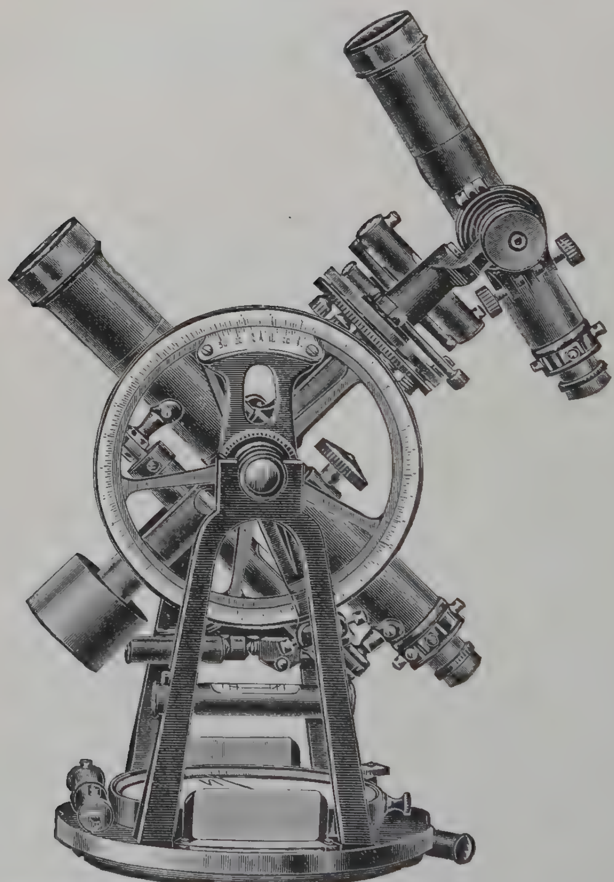
* SECRETARY'S NOTE.—This subject, introduced in 1898 by the paper of Mr. Dunbar D. Scott (*Trans.*, xxviii., 679), was discussed in the two following years (*Trans.*, xxix., 931, and xxx., 783, 803) by many contributors. From Vol. xxx. two important papers on the subject were necessarily held over to this year (see Secretary's Note, *Trans.*, xxx., 1102). These papers, by Mr. Hoskold and Mr. Lyman, will be found at p. 25 and p. 56, respectively, of the present volume. Together with the paper of Mr. Harden (p. 109), and the present contribution of Mr. Scott, they are included, with the whole of the preceding papers and discussions on the subject, in the special volume, "The Evolution of Mine-Surveying Instruments," issued by the Institute this year. Mr. Hoskold's later paper, on p. 716 of this volume, was not thus included, and is not here considered by Mr. Scott, whose remarks, therefore, are to be considered as "concluding" only so much of the discussion as had been published when he wrote. It is, in fact, especially in the wide range which it has now taken, a discussion which can never be concluded, because it will be reopened with every new step of progress.—R. W. R.

† *Eng. and Min. Jour.*, N. Y., vol. lxviii., p. 697, Dec. 9, 1899; also *Mines and Minerals*, Scranton, Pa., vol. xx., No. 6, Jan., 1900.

The solar adapter with the small striding level, used to bring the auxiliary back to a horizontal position after the main telescope has been set for declination, adds only 9 oz. to the weight of the instrument, so that, with a little care, the same counterpoise-weight will answer every purpose.

The diaphragm of the auxiliary, when thus used for solar

Fig. 164.



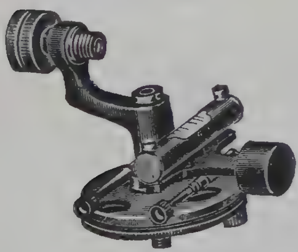
The Interchangeable Auxiliary Telescope Adapted to Solar Work.

purposes, is provided, in addition to the usual cross-webs, with four extra coarse webs, forming a square slightly smaller than the sun's image, as shown in Fig. 166. This arrangement of webs, as Mr. Lyman will see, does not interfere with the successful operation of the auxiliary in mining work; and, indeed, there is no valid objection to the use of cross-webs—though, for the peculiar exigencies encountered in conducting a mine-

survey with an *interchangeable* auxiliary, a single web fulfills every demand and is not a "serious inconvenience," unless the surveyor insists upon doing the very thing I am trying to avoid, namely, observing vertical angles with the auxiliary on top, and computing the correction for eccentricity.

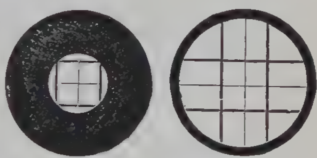
Mr. Lyman is entitled to grateful acknowledgment for the very thorough investigation he has made in response to the last paragraph of my paper,* which was intended to convey more plainly my own estimate of its worth than the presumptuous title would imply. The time available for its preparation in the midst of a busy professional career was so limited as to permit errors and misconceptions to creep in. Of course it is as absurd to suppose that Ramsden had constructed his circular dividing engine at twenty-three, in the second year of his ap-

FIG. 165.



The Solar Adapter.

FIG. 166.



Diaphragm of the Interchangeable Solar Auxiliary.

prenticeship, as that Draper had constructed a transit in the sixteenth year of his age; and the implied assertion that Ramsden had introduced, posthumously, a transit-principle is a self-evident mistake.†

Mr. Hoskold has shown in his second contribution that Ramsden did not complete his dividing-engine until 1773, instead of 1760, as I had it;‡ and while no less an authority than Mr. Stanley is responsible for the citation concerning the introduction of the transit-principle by Ramsden in 1803,§ he is now unwilling to substantiate any part of it, and, in writing

* SECRETARY'S NOTE.—The paragraph here referred to, which formed the conclusion of Mr. Scott's paper in its pamphlet form, was a request for correspondence, corrections, and additional facts. Having served its purpose, it was, for obvious reasons, and in accordance with usual practice, omitted when the paper was printed in permanent form in vol. xxviii.—R. W. R.

† Mr. Lyman's paper, present volume, pp. 88–90.

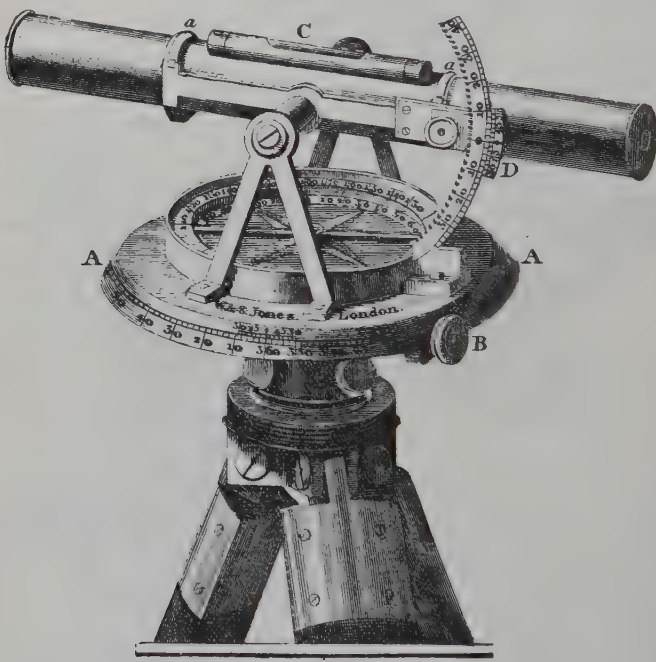
‡ *Trans.*, xxviii., 694 and 697.

§ *Surveying Instruments*, William Ford Stanley, 2d ed., London, 1895, p. 206.

me, seems inclined to forgive us for having detected an inaccuracy in his otherwise studiously prepared and exhaustive work.

Much force was given, in my mind, to this citation, when I found in Adams's *Geometrical Essays*, published six years previously (1797), a description and cut of a miniature theodolite, herewith reproduced in Fig. 167. This is a 4-inch model which Adams designed in 1791, and at least suggests the possibility of making a small transit-instrument by slightly increasing the height of the standards as they occur in the contemporaneous

FIG. 167.



Adams's Miniature Theodolite.

instrument shown in Fig. 16 (*Trans.*, xxviii., 696), and by substituting a better-proportioned telescope.

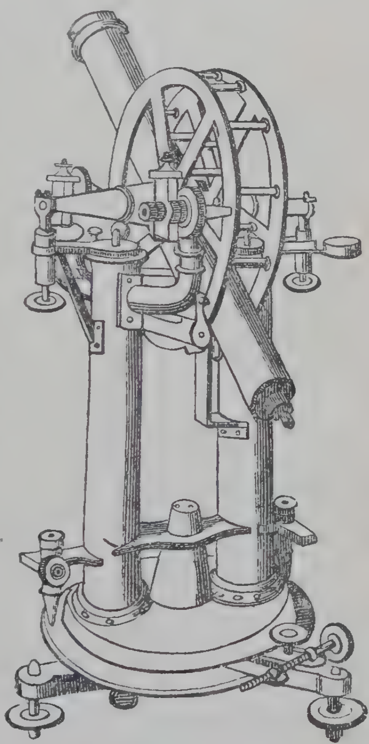
The telescope rested in a sort of cradle, and could be reversed, end for end, by opening the clips, *a*, *a*. The vertical arc was set concentric with the axis of revolution; and while, by the old-fashioned rack-and-pinion screw, the telescope could be made to move through an arc of only from 30° to 40° above and below the horizon, I consider this, in some respects, the most perfect of old English portable instruments.

Dr. Raymond has called attention to the fact that the original astronomical transit-instrument was the invention of Roëmer

(Olaus Roemer, the Danish astronomer) in 1700, though other authorities place the date as early as 1689: for the instrument was described in 1700 in the third volume of *Miscellanea Berolinensia*. In 1704 Roemer combined with it a vertical or altitude-circle, possibly the first of that type of instrument which the English have since designated "alt-azimuth."

The first of this class for the Greenwich observatory was built by Troughton in 1816; and Mr. W. T. Lynn* informs me that the first of the portable type, to the best of his knowledge, is referred to in the sixth volume of the edition of 1830 of the *Edinburgh Encyclopedia*, where there is illustrated and described a portable transit-instrument which Edward Troughton designed in 1810. In the same place he is credited with having contrived a similar one as far back as 1792.

Fig. 168.



8-inch Alt-Azimuth.

Further, Mr. Lynn says there was published in the *Dictionary of Arts, Sciences and Literature* (Abraham Rees, 1819) another model of Troughton's, which bears a very close resemblance to Young's. The only copy of this rare work known to Mr. Lynn is preserved in the British Museum, where they object to having reproductions of any kind made, though I hope subsequently to prevail upon the Director to extend this courtesy to American students. The transit illustrated by Rees has some points in common with the one I have selected from Simms's work† and presented in Fig. 168. The author does not give the date of its introduction;

* Late of the Royal Observatory; now residing at 26 South Vale, Blackheath, London, S.E.

† *A Treatise on Mathematical Instruments*, F. W. Simms, London; 1st ed., 1834; 5th, 1844.

but Mr. W. Simms (now retired from the firm of Troughton & Simms) testifies that it was a regular model when he entered the business in 1832. The azimuth-axis of this transit-instrument was inverted between the standards, as in one of Mr. Hoskold's instruments; but the pillars were of sufficient height to permit a complete revolution of the telescope—a desirable feature not included in the model just referred to (Fig. 75, *Trans.*, xxix., 964).

It would be hardly fair, from what I know at this writing concerning these instruments, to attempt to show that the designs prevalent in early English models were in any way responsible for that of Young, particularly as these so-called altitude- and azimuth-instruments, with their large circles and reading-microscopes, were intended rather for geodetic work than for civil or railroad-engineering. It is noteworthy that, in another work of Simms,* one E. M. Clark advertises to sell "Young's Railway Transit," and recommends it as possessing many advantages over the theodolite for railroad work.

My remarks upon Young's invention were, in a measure, based upon a long-established popular opinion, sustained by such authorities, among others, as Johnson† and Carhart.‡ I do not think the elder Young would claim what was not rightfully his. His grandson, in contributing to this discussion, has been noticeably generous in the apportionment of honors with a fine sense of charity unknown to some of the phenomenal manufacturing inventors who sit in their shops and anticipate the instrumental embodiment of every scientific principle with which the engineering profession has to deal!

Mr. Lyman's researches concerning Draper are highly appreciated; but any attempt to associate his name with the invention and introduction of the transit in America seems to be permanently defeated by the evidence of Mr. B. Jay Antrim, Draper's oldest apprentice, still residing in Philadelphia, who testifies that he was born in 1819, and, at the age of 15, went to learn his trade of Draper, who, at that time, had been in business two years. If Mr. Antrim's recollection be accurate,

* *A Treatise on Drawing Instruments*, F. W. Simms, London, 3d ed., 1847.

† *Theory and Practice of Surveying*, J. B. Johnson, C.E., New York, 1886, 1889, p. 86.

‡ *A Treatise on Plane-Surveying*, Daniel Carhart, C.E., Boston, 1887–93, p. 396.

Young's transit, as shown in Fig. 60,* was on the market a year before Draper became established; and it would further appear that, where I have spoken of Draper's house as founded in 1815,† I am in error, as well as my informant, Mr. Knight, by about 17 years.

Mr. Lyman's heroism in the defence of Mr. Heller (p. 100) is characteristic and commendable; but I do not deserve the imputation of being partial or malicious. I made repeated efforts to obtain information from Mr. Heller in correspondence, and even went to the patient expedient of inducing an acquaintance to call at his office for that purpose, but was not, I regret to say, indulged with the solicited consideration. If, however, after the lapse of two years, he has delivered the desired facts to Mr. Lyman, I am obliged to both for thus enriching the technical value of this investigation.

At first glance, Figs. 159 and 160 in Mr. Lyman's paper seem to contradict my somewhat sweeping statement (*Trans.*, xxviii., 718, top); but it appears that the small structures at the side of the pillars are not intended for the adjustment of parallelism, being only clamping-screws, with unusually long shanks, into which are inserted "safety-pins" to prevent loss. My statement is none the less to be qualified by the fact that the first side-auxiliary which Heller & Brightly introduced in 1871 was capable of being tested for parallelism by four clamping- and four adjusting-screws, in much the same manner, I understand, as that adopted by Saegmuller in 1881 for his solar attachment.

Perhaps that statement ought to be further corrected by a claim of F. E. Brandis, Sons & Co.,‡ who introduced in 1890 the instrument shown in Fig. 169.

The top-telescope of this instrument was attached to the main telescope by the usual small upright pillars and locking-nuts; but in addition to these there was supplied a round capstan-screw base, intended to either increase or diminish slightly the length of the pillars, and so to adjust the telescopes for parallelism. The position of the hubs, as fixed by the makers, was supposed always to insure the adjustment for

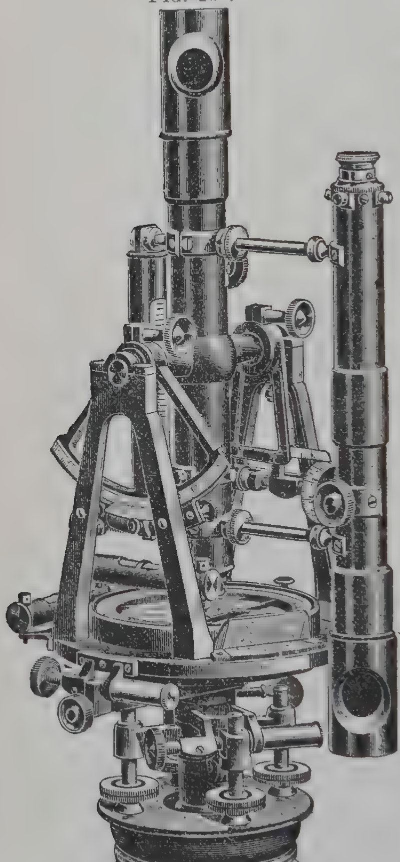
* *Trans.*, xxviii., 744. † *Id.*, p. 704.

‡ Mathematical instrument-makers, 814 Gates Ave., Brooklyn, N. Y.

alignment; but later, in 1894, they made it possible to test this by mounting the pillars on annular straps, which were movable in azimuth.

In 1891 this firm made also, upon the order of Barry Searle, E.M., then of Montrose, Pa., an instrument which he intended should meet all the requirements of solar, mining and railroad-work. In a letter to me, Mr. Searle describes it as provided with a detachable side-telescope and a Saegmuller solar attachment. The side-telescope was provided with a small longitudinal bubble, according to the practice instituted by the Brandis Co. in 1888 for the purpose of insuring a correct replacement of the auxiliary to correspond with the zero of the vertical circle. Mr. Searle's instrument was furnished with an adjustable 120° vertical arc, similar to that in Fig. 169, together with a prismatic eye-piece and stadia-wires. In my original paper* I quoted from Prof. Baker the statement that "stadia-hairs were not introduced in America until after the Civil War." This is incorrect, as the following passage from an American author shows:

FIG. 169.



Brandis Mine Transit.

"The credit of having first introduced this method of measurement in this country would seem to belong to Mr. John R. Mayer, a French-Swiss. It was used by him as early as 1850, and subsequently during his connection with the U. S.

* *Trans.*, xxviii., 721.

Lake Survey. . . . An essay by him in the *Journal of the Franklin Institute*, Jan., 1865, contains a short historical sketch of the development of topographical surveying, and a brief discussion of the principles of stadia-measurements."*

I am not, nor does Mr. Lyman seem to be, convinced by any evidence yet developed that the micrometer of Gascoigne involved the principle of stretching hairs or filaments across the diaphragm, as used by Watt (1771) and Green (1778). Townley says nothing of hairs in mentioning Gascoigne's micrometer; and the citation from Mackenzie, even if it may be considered as authoritative, is not sufficient to prove this point. Mr. Lyman writes me that Grant, in his *History of Physical Astronomy*, says, at p. 452:

"Mr. Townley's micrometer was actually produced before the meeting held on the 25th of July, 1667; and a detailed description of it was subsequently given in No. 29 of the *Philos. Trans.* In principle it exactly resembles the micrometer of Auzout. Two straight edges of metal are made to approach each other at the focus of the telescope by means of a screw, the mechanism being so contrived that the optical axis of the telescope is always situate midway between the two edges. . . . Hooke suggested an improvement upon this micrometer by substituting human hairs for the solid edges."

My observation (*Trans.*, xxviii., 721, top) has yet, I believe, to be disproved, even though, at the time, I had overlooked James Watt. More recently there has come to my notice other literature on the subject,† introducing a new claimant who, with respect to the stadiametric principle, will at least supersede both Watt and Green. At page 619, vol. ii., of his work on surveying,‡ Dr. Jordan says, as one would translate:

"Concerning the history of the stadia, it is reported in *Études théoriques et pratiques sur les levers topométriques et sur tachéométrie*, by C. M. Goulier, Paris, 1892, that the stadiametric measurement was commonly supposed to have been invented in 1778, by Wm. Green, an optician of London, and has been used since 1812, in Holland, by French army officers, and since 1816 in mapping the borders of Savoy. The Italians date the invention still further back to 1674, at which date Geminiano Montanari introduced the practice of placing upon the diaphragm many equidistant threads; and the number of these intervals, for a rod of a fixed length, determined the distance at which it was placed. As an authority for

* *Stadia-Surveying*, Arthur Winslow, New York, 1884, p. 5.

† Prof. E. Hammer in *Zeitschrift fur Vermessungswesen*, xx. Band, Heft 11, 1891; also, the same with addenda in *Zeit. für Instrumentenkunde*, May, 1892. See also Prof. M. Schmidt on "Mensula Prætoriana," in *Zeit. fur Verm.*, xxii. Band, Heft 9, 1893.

‡ *Handbuch der Vermessungskunde*, Dr. W. Jordan, Stuttgart, 5th ed., 1897.

these facts is cited *La livella diottrica* of Dr. G. Montanari, Venezia, 1680, p. 28; and one should also compare *Instrumenti e metodi moderni di geometria applicata*, A. Salmoiraghi, Milano, 1884, pp. 278–279."

The conception of the idea of subtense measurement, with a constant length of rod, plainly belongs, then, to Montanari, while Watt and Green seem entitled to only the credit of having introduced the improved method as we use it to-day.

I am reminded here to touch briefly upon the subject of platinum wires. While I have no authority or inclination to dispute the fact that Heller & Brightly were first to introduce these in America, their original introduction as a substitute for spider-webs on the diaphragms of telescopes certainly belongs to Dr. Wm. Hyde Wollaston, a celebrated English scientist, who died in 1828. He received a medal of the Royal Society for his process of manufacturing platinum; and his paper on its malleability was published in the *Philos. Trans.* the year following his death. It is now hinted that he acquired the secret of rendering it malleable from one Thomas Cock.

Because Digges incidentally recommended his *theodelitus* for use in mines in a short note, in which his only instructions are to the effect that "the diligent practizioner shall be able of himselfe to invent manifolde meanes to resolve" the problems confronting him, Dr. Raymond omits to give v. Hanstadt the credit of having written the first exclusive treatise on mine-surveying, in which the theodolite is recommended in preference to all other instruments.

At any rate, with respect to the hollow brass cylinders spoken of, I feel impelled to take exception to the foot-note in the course of Dr. Raymond's remarks (*Trans.*, xxx., 800), as confusing. While the *Spreitzen* or gang-plank is the same in each case, the methods of setting-up are very different; and to distinguish these features I submit a cut of Möhling's *Eisenscheibe* and its support (Fig. 170), with a few extracts taken from his work.*

"The *Eisenscheibe* differs from the astrolabe only that it is provided with a ball-and-socket joint beneath the center, and, in place of the diopters, is supplied with two similarly constructed lineals, having hooks at the outer ends and pivot-joints at the center.

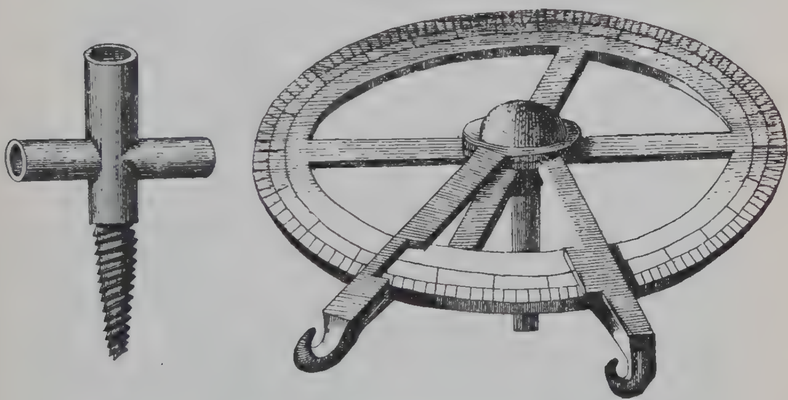
* *Anleitung zur Markscheidekunst*, Johann Möhling, Wien, 1793, p. 155.

"In the beginning of a survey the *Kreutzschraube* (cross-screw) is set firmly into the plank of the second station. After the shank of the instrument has been inserted into the socket of the support, one of the arms is connected by a cord with the first station, and the instrument is swung upon its axis until the zero of the graduations coincides with the index of this arm. The second arm is now connected with a cross-screw placed at the third station in the same manner; and the indicated angle on the plate is the one sought.

"The inclination of the cord is determined by the *Gradbogen*, and the distance by measurement, in the usual way.

"Because the instrument must sit very securely, on account of the tension in the cords, we cannot use a tripod, as with the astrolabe, so that a very solidly wedged plank is necessary, and this is especially true since one must be certain of placing the instrument precisely at the point to which the cord had been previously stretched."

FIG. 170.



Möhling's *Eisenscheibe* and Support.

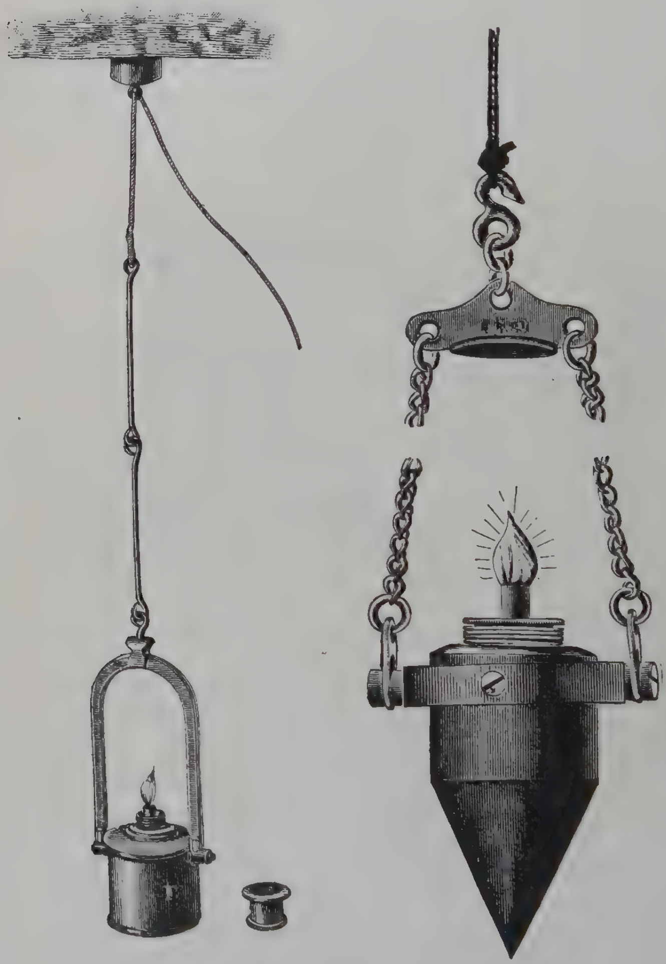
So far as I know, Möhling's form of support is unique; but the *Spreitzen* method of setting-up is very old, and probably dates back to the time when the astrolabe was first employed in mines. Another application of it (Fig. 172), in which no holes are bored, I shall include in the short discussion on the plummet-lamp of Mr. Coxe, which I now beg leave to submit.

The plummet-lamp, as introduced in America by that versatile engineer, Mr. Eckley B. Coxe, I infer, was the more highly civilized resultant of an old German method, taught him while he was a student at Freiberg.

Weisbach's hanging lamp, reproduced here in the first part of Fig. 171, is selected from his work of 1859; and I have no doubt that, being his invention, it also occurs in the first edition (1851). Its construction is so apparent that no special explanation need be given.

He recommended it for surveys where, in open chambers and the like, the instrument had to be mounted upon a tripod, except for sights of less than 3 *Lachter* (fathoms). In that case, he explains, an attempt to bisect the flame is not attended with

Fig. 171.



Weisbach. Coxe.

The Hanging Lamps of Weisbach, 1850, and Coxe, 1870.

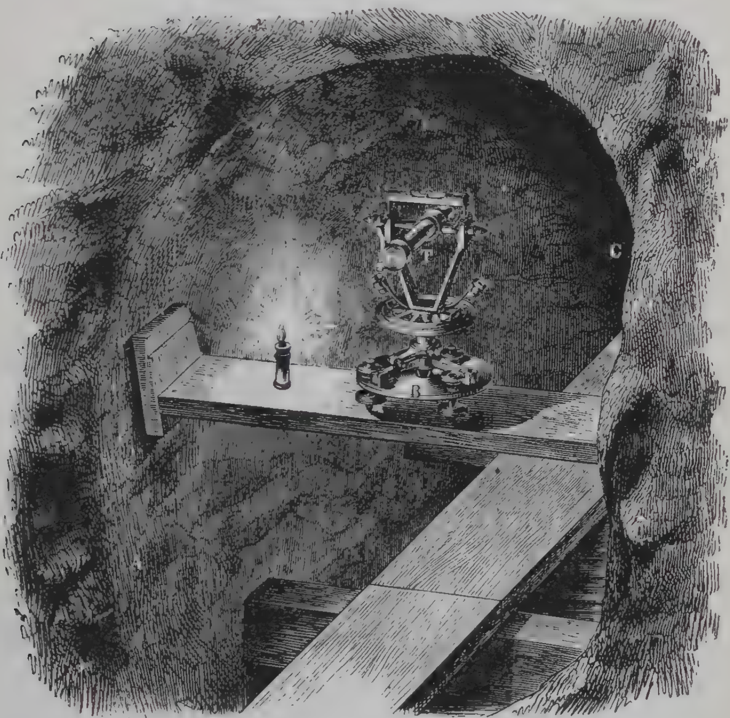
good results; and in such cases the plumb-line only should be sighted.

Weisbach always greatly preferred the *Spreitzen* method of setting-up, as shown again in Fig. 172, and the *Setz-signal-lampe*

(Fig. 173), which, as he contrived it, was, in reality, the base of a theodolite peculiarly designed to carry out this practice. His special argument in favor of the *Spreitzen* system was based on the fact that the plank provided room, not only for the instrument, but also for the hand-lamp and the note-book, as occasion demanded.

The *Setzlampe* was a brass plate with a central circular

Fig. 172.



Weisbach's *Spreitzen* and *Setzlampe* System.

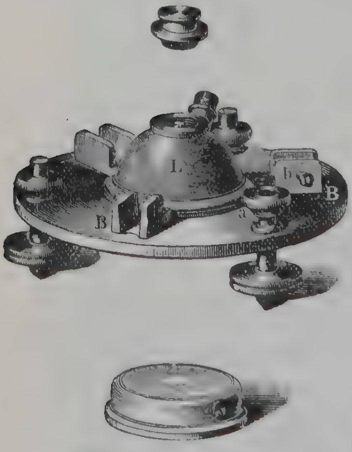
socket, into which the box-bubble was first placed, and then, when the plate was perfectly level, the oil-cup and burner. To insure a permanent adjustment in this respect, the small nuts on the upper shank of the leveling-screws were screwed down tightly against the plate.

When a sight had been taken upon the flame, the lamp was removed, the instrument was brought forward, and the legs were clamped into the saddles, B, B, by the little set-screws at

the side. The circular base of the theodolite was also designed to fit perfectly into the lamp-cavity of the plate.

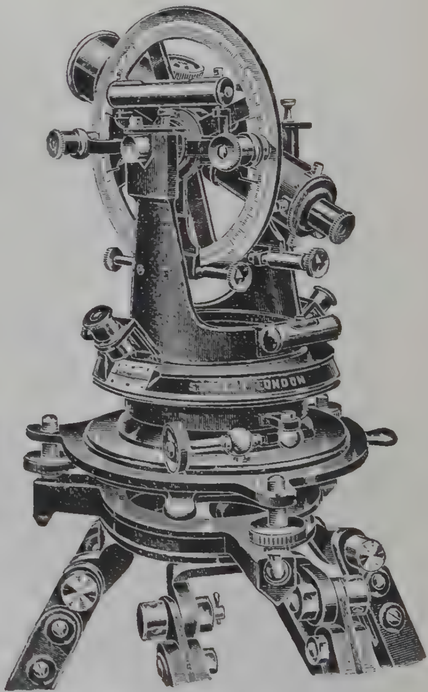
This is another instance of the three-screw leveling-method. Not feeling competent, I shall not attempt to discuss that point further, but will rather leave the exposition of its merits to Mr. Stanley, who I trust will favor us eventually with a more extensive account of his research in England and on the continent of Europe. In 1870 Stanley introduced a special form of theodolite, intended to be universal in its application, which he termed the *geodolite;* but for mining work it was much too tall and weak, so that the model was abandoned. Recently he has come out with something novel in the way of a nadir mining theodolite, shown in Fig. 174, which invites special attention to the three-screw argument, as well as the shifting center in connection with this construction.

Fig. 173.



Weisbach's *Setzlampe.*

Fig. 174.



Stanley's Nadir Mining and Railroad Tunnel Theodolite.

In the Stanley 4-in. model (Fig. 174), the outside diameter of the vertical axis is $2\frac{3}{4}$ in., the clear central aperture $2\frac{3}{8}$ in., and the range of the telescope on each side of the nadir 5°. The distances between the leveling-screws mark a triangle of

$6\frac{3}{4}$ in. on a side, and the entire weight of the instrument alone is 16 lbs. The horizontal axis of this instrument is pierced to permit the diaphragm to be illuminated by a bracket-lamp; but I regard such lamps as abominable excrescences, and the perforation of the horizontal axis as a reckless novelty, for mining work. The damp atmosphere of a mine should never be allowed to enter a telescope in this way, to film the lenses with moisture and relax the spider-webs by virtue of their hygrometric properties. Even an objective reflector is unnecessary; for by simply flickering the candle-flame a short distance in front of the objective, one can sufficiently discern the cross-webs until he gets them bearing on an illuminated plumb-line or station.

Concerning my own instrument, again I refrain from extended discussion. I have, perhaps pardonably, elevated it to lofty dignity among other mining instruments, because it embraces everything that I consider essential for accuracy, simplicity, rapidity and completeness. That, however, is a purely personal opinion. Others, after studying its features, will accept or reject it as they choose. I have absolutely no pecuniary interest in inciting enthusiasm anywhere.

It is not improbable that this general topic will be pursued indefinitely by other members and outsiders, and even I may ask permission to appear again; but, before I finish this contribution, I wish to make ample acknowledgment of my gratitude for the valuable assistance furnished me by the many gentlemen who have given up their time at my peremptory demand. To make special mention of a few would be an injustice to the rest, and to enumerate all, an imposition upon the space available in these *Transactions;* but I hope each may feel himself repaid by the result of the labors of all, and that the information thus collected may be of service to mining students now and hereafter.

The Origin of Ore-Deposits.

Continued Discussion of the papers of Van Hise, Emmons, Weed and Lindgren, *Trans.*, xxx., 27, 177, 424, 578. See also the papers of Vogt, Kemp, Rickard, Blake and Lindgren, at pp. 125, 169, 198, 220, 226, and also the final contribution of Prof. Van Hise, p. 284 of the present volume. All the foregoing, together with the discussion here following, are included in the special volume, "The Genesis of Ore-Deposits," issued this year by the Institute.

H. Foster Bain, Des Moines, Iowa (communication to the Secretary):* The zinc- and lead-deposits of the Mississippi valley, which it has been my fortune to study, give particularly good examples of many of the principles of ore-deposition formulated by Prof. Van Hise. Perhaps there is nowhere clearer evidence supporting his fundamental tenet, that ore-bodies are to be regarded as a result, and as merely one of the phases, of the work of underground waters. The facts regarding the mines of the upper Mississippi valley have been given in some detail for Wisconsin by Prof. Chamberlin† and, more recently, for the mines west of the Mississippi by the Iowa Geological Survey.‡ Fortunately, also, the processes of underground water-circulation have been studied in some detail in connection with the investigation of artesian waters throughout the region.§ In Missouri and Arkansas the mines and ore-bodies have been much studied;|| but the general problems of the circulation of underground waters have been neglected. During the season just closed the writer has been engaged in a re-study for the United States Geological Survey of the zinc- and lead-deposits of the Ozark region, with special reference to those of the Joplin area; and his full report is now in preparation. It has been interesting to note how fully the statement that the ore-bodies result from the general action of underground waters is

* Published by permission of the Director of the U. S. Geological Survey.

† *Geology of Wisconsin*, vol. iv., pp. 367–571.

‡ Leonard, A. G., vol. vi., pp. 9–66. Calvin and Bain, vol. x., pp. 480–597.

§ Leverett, F., *U. S. Geol. Surv., Monograph* xxxviii., pp. 550–784. Norton, W. H., *Iowa Geol. Surv.*, vol. vi., pp. 115–428.

|| See especially A. Winslow, *Mo. Geol. Surv.*, vols. vi. and vii.; and W. P. Jenney, *Trans.*, xxii., 171–225.

here substantiated. Treated merely as parts of a problem of water-circulation, many of the difficulties regarding the ore-deposits vanish.

In brief, the Joplin area is one in which flowing wells would occur, if it were not for the numerous deep fractures which, permitting the free outflow of springs, has had the same effect, in causing loss of head, as the placing of wells too close together. The gathering-ground is the central plateau of the Ozarks; the overlying impervious layer is the Eureka-Kinderhook shale, which divides the Carboniferous from the Siluro-Cambrian. The aquifers are the porous dolomitic limestones and interbanded sandstones of the Siluro-Cambrian. At an earlier stage much of the water was transmitted down the dip through the Carboniferous limestones under a coal-measure cover. This earlier circulation seems to have been more important in bringing about the recrystallization of the limestone, and probably to some extent its replacement by chert, than in causing actual ore-deposition. The coal-measure cover is now, however, cut through. The present actual difference in head is about 700 ft. Water now rises in the Carthage well from the Silurian limestones to within a few feet of the surface, and in the Redell deep-rock well, at Joplin, to within 80 ft. of the surface.

That the ore-bodies were deposited by waters rising from these deeper limestones is proved by the following facts:

(a) The ores are everywhere associated with great quantities of dolomite. The lower limestones are dolomitic, while the Carboniferous limestones (the immediate country-rock) are not. It is also true that the Carboniferous limestones show no dolomitization away from the region of the ore-bodies, even though they have clearly been worked over by circulating water. The magnesia was evidently brought in at the same time as the ores. The magnesian limestones of the Siluro-Cambrian, in both the upper and the lower Mississippi regions, are almost everywhere associated with more or less ore. The Carboniferous non-magnesian limestones are nowhere associated with ore, except in this particular region, where, as has just been pointed out, the circulating waters passed in their course from the one to the other. These conditions of circulation have been stable for a long time.

(b) The ore-bodies of the Joplin region stand in relations, usually close, with a system of fractures and faults of such extent and character that we cannot but assume that they have broken the underlying Eureka-Kinderhook shale and allowed the intermingling of the two circulations above and below it. These fracture- and fault-planes have been much obscured by the irregular manner in which the Carboniferous limestone and its contained chert breaks up, and the very considerable solution which has taken place in this limestone. Nevertheless faults occur, of a minimum throw of 80 ft., traceable across the country for a mile and a half, and are not to be confused with the effects of mere settling as a result of surface-solution. Neither are faults of 140 ft. throw, accompanied by overthrust, to be referred to this category, or confounded with the effects of the pre-coal-measure period of erosion. Such faults were present before the concentration of the ore; and the ore-bodies stand in close relations with them. They served as the main channels for the upward flow of the ore-bearing waters. Once in the Carboniferous limestones, the solutions wandered widely, and deposited ore under many different conditions.

In the upper Mississippi region, the fact of general artesian conditions on the flanks of the Wisconsin axis is well recognized. The presence of alternating pervious and impervious beds affords several distinct circulations, one above the other. Differences in pressure, composition of the waters, etc., indicate, so far at least as the territory west of the Mississippi has been studied, that each circulation is practically distinct. The ores of the region are mainly found in the Galena-Trenton limestone, and especially in the upper, dolomitic portion, to which the name Galena is specifically applied. This lies below a heavy bed of practically impervious shale, to which the terms Maquoketa, Cincinnati, and Hudson River are variously applied. There are minor and local beds of shale in the Galena-Trenton, and a thin but persistent bed cuts it off from the St. Peter sandstone below. At an earlier period, as Prof. Van Hise shows, the waters in the Galena-Trenton were under hydrostatic pressure; but now erosion has cut deep into and through the ore-bearing strata, and for a long period of time the movement of the waters and the concentration of the ores has been downward. There are locally evidences of movement in the oppo-

site direction, as at the Kane Brothers' mine near Dubuque; and throughout the district there are certain phenomena which are best explained by the suggestion of an earlier concentration by water under considerable head. The later effects of present conditions, however, are, in most of the Iowa mines, the more striking.

Prof. Van Hise has emphasized the importance of the impervious layer, not only as directing the general course of underground circulation, but often as closely connected with the deposition of the ore. In both the regions under discussion examples of this phenomenon are exceedingly common. In the Joplin region the constant association of ore with the small outliers of coal-measure shale, and the common tendency of the ore in soft ground to "make" against a bar, are essentially phenomena of this sort.

Decrease of temperature and pressure cannot be invoked to explain the ore-bodies in either region. There are neither hot nor warm springs in either, nor is there any independent evidence that any such have ever existed. The reactions involved in the genesis of the ores are all such as take place under present surface-conditions; and, when the time and quantity of water are taken into account, there is no necessity for other agents. In the Dubuque (Iowa) region, studies of the artesian wells make it clear that the circulation did not extend to a depth sufficient to make pressure quantitatively important. In Missouri, if the waters be limited practically in their lower circulation by the crystalline rocks, the same is true. There is no independent evidence that any considerable portion of the circulation extends into the crystallines; and many facts suggest the opposite view.

The mingling of solutions has been especially important in producing deposition in both regions. In the Dubuque and Wisconsin regions, this is shown in the fact that the main ore-deposits are found at points where two crevices cross each other. For instance, in the Stewart's Cave mine, near Dubuque, there are two parallel E.–W. crevices, about 60 ft. apart. Along the south crevice a great deal of lead has been found; in the north crevice, practically none. In the south crevice, ore is found only at points where there are cross-crevices. In fact, the south crevice always carries ore where there was a chance

for the waters from the other crevice to come in. In this case, one crevice evidently carried the solution which contained the mineral, and the other the precipitating agent. Where the two solutions came together, an ore-deposit was formed.

In the Joplin region, the same thing was clearly shown in the fact that the great deposits of zinc are found largely in the Carboniferous limestones, which are cut off from the Cambro-Silurian by a series of shale beds. It is only where these have been broken across by faults that ore-deposits are found. The Carboniferous limestone carries large amounts of bituminous matter—so much that, in certain of the mines, when the rock is broken it looks like asphaltum-mastic. This bituminous matter is widely distributed throughout the Carboniferous limestone of that region, and the waters circulating through these beds become highly charged with it, and hence are reducing agents. The sulphate solutions coming from below have been reduced to sulphides in the limestone, making the ore-deposits.

The general principle of the reduction of one sulphide by another does not seem to have been very important in the Missouri region, although we do find evidence there of that process. In the Iowa region, however, it has played a very important part. At the Pike's Peak, near Dubuque, it is constantly found that in the little cavities in the rock there is a lining of iron sulphide; that is, the iron sulphide is between the zinc and the rock, and apparently acted as the reducing-agent. The iron sulphide was there first, and the zinc sulphate, coming later, has been reduced by it to zinc sulphide.

The general principle of secondary enrichment finds exemplification all through the Joplin region. One of the best cases is the Boston-Get-There mine, at Prosperity, just south of Cartersville. At this mine about 15 acres have been mined out underground, for a thickness of from 10 to 20 ft. The mine is in the top of a big body of chert, underlying limestone. Between the layers of original white flint are thin sheets of black secondary chert; and in these bands the ore is found. The beds dip slightly SW., so that the waters falling there, as shown by the drainage of the mines, flow from NE. to SW. Going NE., up the dip, we encounter more galena and less zinc blende; and often we can find where the little pieces of zinc blende have

been dissolved out of the chert matrix by the water, leaving cavities which have the characteristic form of the zinc blende crystals. It follows that blende has been taken away by the underground waters, and carried down the dip. Farther down the dip we find cavities filled with clear, sharp and apparently new crystals of zinc blende. We have here an instance of the removal of zinc blende by the oxidizing waters and its redeposition farther down the dip.

The general processes of secondary concentration and enrichment are also exemplified in the common fact that the great bodies of zinc blende occur at and below the groundwater-level, which, at Joplin, occurs almost at the surface. Until pumping was carried on vigorously, water was found at a depth of about 30 ft. Now the ore is mined at depths of 150 and 200 ft. by pumping out the water. That the general process, so far as the formation of the richer bodies is concerned, has been one of concentration downward, is shown in the fact that at the surface, and in the small deposits below the surface, where we have direct evidence of oxidation, we commonly get galena, while at lower depths great bodies of zinc sulphide occur. Of the common sulphides, galena, blende and pyrite, the galena is the last to go into solution in the presence of oxidizing waters; hence, where we have the three together, the general effect of the downward-flowing waters is to carry the zinc blende away from the galena, leaving the latter at the surface, and redepositing the zinc in the lower rich bodies of ore.

Another important principle, which is well exemplified in the region as a whole, is, that the form and character of the ore-body are controlled by the character of the rock in which the ore occurs. This is largely due to the fact that the fractures in rock are controlled by the character of the rock. Homogeneous rocks will yield under stress more uniform fractures than heterogeneous rocks. In the Joplin region, the Carboniferous rocks are interbanded limestones and cherts, which break irregularly; while the Cambro-Silurian limestones are homogeneous, and break with more regular fractures, like the Wisconsin limestones. The result is seen in the very irregular form of the Joplin ore-bodies as contrasted with the usual regular vein-like form of the deposits in the central, and portions of the south-eastern, districts.

The ores of the Ozark region in general, away from the southwestern district, were only studied for the light they would throw on the problems of the latter region. They are different in form, because they occur in a different sort of rock; but enough was seen to justify the statement that they are quite as closely dependent upon the general circulation of the underground waters as are the Joplin ores. In all essential particulars they follow the same general principles. The details of the investigation naturally cannot be given here.

Dr. Charles R. Keyes, Des Moines, Iowa (communication to the Secretary): It is not too much to say that Prof. Van Hise's paper marks a new epoch in the science of ore-deposits. Few who are not expert petrologists, in the most modern sense of the term, can fully appreciate the profound significance of his remarks. His paper shows more conclusively than ever before that, if we are to make great advancement in the study of ore-deposits, it must be largely along geological lines. Geological occurrence, geological structures and geological relationships come in for first consideration.

It is a startling statement that ore-bodies are essentially surface-deposits, that is, they are mainly confined to the brittle shell of the globe,—that zone near the surface commonly called by the geologist the zone of fracture. Few of us are fully prepared to accept this proposition without some reserve. Yet a little reflection will show that it could hardly be otherwise. The phenomena connected with ore-deposition are merely special cases of a more general problem, with which geologists have long had to deal.

Specially opportune is Prof. Van Hise's discussion of the upper limit of groundwater, concerning the relations of which to the position and character of ore-bodies, it removes at once many obstacles which have long stood in the way of satisfactory explanation of apparently anomalous phenomena. Any change of position of this groundwater level necessarily produces important changes in the mineralogical nature of the ores. Yet some orogenic movements are known to take place much more rapidly than the ores are altered by weathering influences; and consequently we often find a marked discrepancy between the groundwater-line and the local character of the ores that we

should expect to find. In the broader field of general rock-alteration we assume the truth of the observation made by Wadsworth that all such changes are from a less stable to a more stable condition. But this does not express the full significance of the phenomenon. The conditions themselves are continually changing. The process is essentially continuous, yet sometimes in one, and sometimes in directly the opposite, direction, as is the case with the better understood analogous processes in what we call the organic realm.

I am not sure that I fully understand the statement of the third premise of the paper, that "by far the major part of the water depositing ores is meteoric." In the absence of the full explanation it may be well not to discuss this point. However, this statement very materially broadens our ordinary conception. There is, perhaps, need of a new term here. But, as it stands, and taking into consideration the related "minor part" in all its aspects, the statement, reduced to its lowest logical terms, merely declares that water is water.

Although Prof. Van Hise's paper contains but little regarding the classification of ore-deposits, it has an important bearing upon that subject; and I am particularly interested in this aspect of it, because it is along the same line that I have been working for some time in a humble way, and it is on practically the same basis that I presented the first outlines of my own classification in my paper, read at the same meeting of the Institute.*

When Prof. Van Hise, summing up the situation, says that "for many ore-deposits a complete theory must be a descending, lateral-secreting, ascending . . . . theory," he certainly states a conclusion from which there is no escape. We can only attain an adequate explanation of ore-deposition by considering all of these currents, sometimes working independently, perhaps, but usually operating in conjunction and practically contemporaneously.

In my own work I was confronted by the labyrinthine complexity of any classification based directly on the metamorphic processes, as we know them operating upon the rocks. Prof. Van Hise appears to be profoundly impressed in the same manner.

* "Origin and Classification of Ore-Deposits," *Trans.*, xxx., 323.

My own position is that any classification of ores in order to be useful to the fullest extent must be, first of all, simple; secondly, capable of being readily applied in the field; and finally, useful as a guide to proper exploitation. No matter how refined and well-fitting a scheme we have, if it does not meet these three requirements, it will not be adopted or even be considered by practical men.

I need not here repeat the further arguments and explanations of these propositions which I have set forth in my paper, above-mentioned; and I content myself with saying, in conclusion, that if further progress is to be made in the study of ore-deposits, it must be along the lines laid down by Prof. Van Hise.

PROF. R. BECK, Royal Saxon Mining Academy, Freiberg, Saxony (communication to the Secretary): The paper of Prof. Van Hise represents a great step of scientific progress, in that the circulation of underground waters has never before been presented with such clearness, in the light of modern chemical and physical knowledge. The theories of the formation of ore-deposits which follow the author's general survey of the currents and solvent power of atmospheric waters in the earth's crust do not, indeed, seem to be novel, being essentially an amplification of Le Conte's views; but the proofs adduced in their support are in many particulars so original that no one can read without profit this portion of the paper.

Entirely new (though largely in agreement with the papers of Emmons and Weed, presented at the same meeting of the Institute) are the sections dealing with the formation of the rich sulphides of the precious metals, and especially the regeneration of normal sulphides, such as galena, etc., in vein-zones immediately beneath the ground-water level.

Nevertheless, it appears to me that Prof. Van Hise, in the course of his most instructive exposition of unquestionable, yet still locally limited, phenomena, has been too much biased in favor of the "descensionists." This is indicated by the small importance which he attaches to the intimate genetic relation between epigenetic deposits and the plutonic hearths of the earth's interior.

In my treatise, just published,* I have proved from many in-

* *Lehre von den Erzlagerstätten*, Leipzig, 1901.

stances that the formation of ore-veins is frequently a direct consequence of the plutonic intrusion, particularly of acid magmas. Prof. Van Hise recognizes such a relation only to this extent, that atmospheric waters, in their downward course, may have happened to reach eruptive masses, perhaps long since solidified, though, in common with the enclosing rocks, still warm, and may have extracted the disseminated mineral compounds from these old magmas. But we still hold to the conception of an immediate relation in time also. We hold as a primary principle that the gases and vapors contained in the fused magmas, and escaping as these cooled, must have played, as carriers of metallic compounds upwards from the region of the plutonic hearth, a very active part. Especially does the study of contact-metamorphism (*e.g.*, at Kristiania, Norway, in the Banat, and at Berggiesshübel in Saxony) strengthen us in this conviction.

As concerns the cassiterite-veins, this view has many adherents. The direct connection between granite intrusions and the formation of veins carrying tin-ore, I have lately been able to establish still more firmly by showing that at Zinnwald, in Saxony, small cassiterite-veins in the periphery of the granite mass of that district are cut by veins of a fine-grained "vein-granite." The deposition of the tin-ore must therefore have been still in progress at the time of additional intrusions of granite from below.

But there is by no means in the *Erzgebirge* a sharp separation between the veins of cassiterite and those of silver-lead-ores. The latter sometimes contain constituents characteristic of the tin-ore group; and they are likewise connected with the intrusive plutonic masses of the *Erzgebirge.*

The latest work of American observers upon gold-veins, especially that of Spurr and of Hussak (Brazil), has shown that, for many gold-quartz-veins also, there must exist a very intimate genetic and chronological connection with deep plutonic intrusions. Thus, the nature of many gold-quartz-veins is closely allied to that of the pegmatites—those peculiarly-modified derivatives from deep granitic hearths. In this department also, the purely hydro-chemical theory of Prof. Van Hise appears to be inadequate. The facts suggest too strongly an active participation of subterraneous plutonic masses, par-

ticularly through the expulsion of gases, which may have become mixed with ascending waters.

The meritorious work of Messrs. Emmons and Weed, as shown in their papers,* opening as it does a wide field hitherto unknown, or, at least, entirely neglected, will certainly call forth a long series of confirmatory observations. I have not yet found time to ascertain by closer study to what extent our Freiberg district shows secondary sulphide-enrichment by descending solutions. To a limited degree it is certainly present, *e.g.* in the not infrequent thin, sometimes dendritic, coating of silver-glance or native silver on cross-fissures in older vein-fillings, or the druses of beautifully crystallized rich silver-ores in geodes. The crystals of stephanite in the interstices of a breccia in the Himmelsfürst mine, for instance, may fairly be considered as later deposits from descending waters. But it is very doubtful, to say the least, whether our great bonanzas belong in this category. In our case, the question is exceedingly complicated, because the ground-water level has probably been more than once displaced, upward or downward.

Our veins, admittedly formed, for the most part, before the Cretaceous period, may have stood long already, at the time of the great Cenomanian disturbance and erosion, with their upper zones above ground-water level. For only a couple of miles from Freiberg, and about at the same altitude, Cretaceous strata are now found lying upon the gneiss (in that locality deeply decomposed) which, near the town of Freiberg, encloses the veins. Thick masses of Cenomanian Cretaceous sandstones were unquestionably denuded again, in the Freiberg mining district itself, during the Tertiary. The vein-zones which, during the Cretaceous, were crowded deep below the ground-water level, must have been elevated again, therefore, in Tertiary times, above that level.

Exact observations and assured conclusions are moreover made difficult, practically, by the circumstance that, at the present time, only those vein-zones are being mined which lie far below the natural ground-water level.

Students at a distance might, perhaps, infer from descriptions of this district that the rich sulphide-ore-bodies found in our "barytic lead-ore formation," at its crossings with the veins of

---

* *Trans.*, xxx., 177 and 424.

the "pyrite-blende-lead-ore formation," belong in the category of enrichments so well described by Emmons and Weed. The mineralogical composition of these bonanzas, with its abundance of argentite, proustite, pyrargyrite, acanthite, stephanite, polybasite, and native silver, is indeed similar to that of the bonanzas in Montana silver-veins. Yet the veins of our barytic lead-ore system do not at all exhibit the characteristics of "descensive" formations—the abundance of fluorite alone contradicts such a view. The rich ore-bodies at the intersections referred to must be rather explained as simply due to chemical reaction between the masses of normal sulphides (pyrite, galenite, chalcopyrite, arsenopyrite and sphalerite) in the older veins, and the ascending solutions in the fissures of the later barytic lead-ore system. Emmons himself* concedes the probability of such reactions in many cases.

However great may be our pleasure and praise in connection with these latest victories of science, we must nevertheless be warned not to attach to them too universal a significance.

With regard to Mr. Lindgren's paper,† I will frankly say that since the death of Stelzner nothing has appeared in which the methods of microscopic-chemical research have been applied with such splendid success to the subject of ore-deposits. I agree (with insignificant exceptions) so thoroughly with the conclusions which the author has drawn from his brilliant investigations, that it would be useless for me to offer at this time any detailed criticisms. I can only express my delight that Stelzner's method has found in Mr. Lindgren an adequate American representative, master at the same time of the European literature of the subject.

L. DE LAUNAY, Professor at the École Supérieure des Mines, Paris, France (communication, translated by the Secretary): The ideas set forth by Mr. Emmons‡ on the secondary enrichment of ore-deposits, and by Mr. Walter Harvey Weed§ on the enrichment of mineral veins, agree almost entirely with my own; and I can only congratulate myself upon finding their observations so completely in accord with those I have had occasion to make, and thank them for the very kind way in which they have been good enough to cite my writings. I have recently twice reiterated my opinion on these subjects:

* *Trans.*, xxx., 217. † *Id.*, 578. ‡ *Id.*, 177. § *Id.*, 424.

first, in an article in the *Revue Générale des Sciences** on "The Variations of Metalliferous Veins in Depth;" secondly, in a little text-book on practical geology† (in the chapters on superficial formations and the alterations of outcrops, pp. 50 to 72). I have, therefore, little to add. As I have said in these essays, I attach more and more importance to the phenomena of secondary alteration, which have produced a number of important modifications (whether enrichments or impoverishments) in those portions of metalliferous deposits accessible to exploitation; and I fully adopt the conclusion of Mr. Weed as to the necessity of taking very careful account of these phenomena in practical and industrial estimates. I think, likewise, that in these secondary and comparatively recent reactions should be sought the interpretation of many of the phenomena of substitution, lateral alteration, or metasomatism, in the form in which they are now observed; while I continue to admit, with the school of Elie de Beaumont and Daubrée (to which Mr. Waldemar Lindgren brings valuable support), the primary influence of volatile mineralizers. These must have prepared the way by introducing into the enclosing rocks, or simply by depositing in the vein-fissures, elements such as sulphides, fluorides, chlorides, etc., which subsequently, dissolved anew by the circulation of superficial waters, have rendered to the latter essential aid in the processes of alteration. In this manner have been produced the large altered zones which are seen, for example, around pyritic masses in the south of Spain. This point I have fully elaborated in my "Contribution to the Study of Metalliferous Deposits."‡

In order to formulate the study of the phenomena in question, I have been led to distinguish in a very general way, in the alterations of terranes and of deposits, three zones (from the surface downward) which correspond rather to those of Mr. Weed§ than to those of Mr. Emmons,|| the two first zones of Mr. Emmons (the reality of which I am far from denying)

* For 1900; p. 568.

† *Géologie Pratique.* Published by Armand Colin, Paris, 1900.

‡ A book of 116 pp., Paris, 1877.

§ "Enrichment of Mineral Veins by Later Metallic Sulphides," *Bull. Geol. Soc. of Am.*, vol. xi., p. 181 (1900); "Enrichment of Gold- and Silver-Veins," *Trans.*, xxx., 424.

|| "Secondary Enrichment of Ore-Deposits," *Trans.*, xxx., 177.

having been comprised in the first of mine; and I have thus defined them:*

1. First superficial zone of *oxidation*, subject, in its upper part, to physical disintegration: a zone characterized by the peroxidation of iron, and, in the case of metalliferous deposits, by the presence of native metals, oxides, carbonates or chlorides (Mr. Weed's "zone of weathering").

2. The far more important zone of *cementation*, of *de-calcification*, and, more generally, of *complex chemical reactions* (such as the formation of secondary sulphides), liable to show at its base an increase of certain substances, which have been dissolved in the upper part and carried away by the descending waters (the "zone of enrichment").

3. The zone of *unaltered equilibrium* (unchanged sulphides), below the hydrostatic level (the "zone of primary sulphides").

With regard to the process of this alteration, I believe with Mr. Emmons that we ought not to attribute too absolute a value to what is called the hydrostatic level ("ground-water level"), and I have insisted at different times in my "Géologie Pratique" (pp. 52, 152, etc.) on the necessary irregularities of this so-called "level," due to the variable structure of the terrane, and leaving, for instance, beneath a former hydrostatic surface, a zone in which the circulation of surface-waters rich in oxygen and carbonic acid could still take place.

Moreover, it must be noted that, even in the deep zone, the waters could not be absolutely still or incapable of exercising oxidizing chemical reactions, especially if there be great fissures or faults, permitting the introduction and rapid circulation of waters from the surface, such as appear to exist as correlatives, opposed to the ascent of thermal waters,† and as Mr. Weed has well pictured in his Fig. 1.‡ This may explain the abnormal occurrence of certain alterations and secondary enrich-

---

* *Géologie Pratique*, p. 54; *Revue Générale des Sciences*, 1900, p. 568.

† *Traité des Sources thermo-minérales*, Baudry, Paris, 1899); chapters on the origin and outflow of thermal springs, in which I have called attention to the fact that, to constitute a thermal spring, there must exist, below the hydrostatic level, an active circulation which I have compared to that which might be produced in a pipe-elbow, plunged in a basin of water (*op. cit.*, pp. 23 to 31). The moving waters thus rapidly brought by accident into contact with the lower portion of a deposit might exercise upon it an unforeseen metamorphosis.

‡ *Trans.*, xxx., 428.

ments more deeply situated than might have been at first expected. Here is a very interesting fact which Mr. Weed deserves the credit of bringing to light.

Perhaps also, besides the descending waters, the ascending waters, heated by their deep circulation, or even by contact with eruptive phenomena, have in certain cases played a part which their high temperature may have augmented, although we may suppose them to have been robbed of oxidizing reagents by their subterranean circulation. We know, indeed, that Daubrée observed at Plombiéres, Bourbonne, etc., evident reactions of this kind, produced upon metals by prolonged contact with thermal waters of extremely low mineralization; and certain minerals, especially, which may be considered as secondary in copper-deposits, are produced under these conditions:—secondary sulphides such as those studied by Mr. Weed, who has elsewhere mentioned the possibility of this intervention of hot volcanic waters.

Furthermore, as I have long since remarked, when we are confronted with secondary reactions, the persistence of which in depth is surprising, and appears to contradict existing theories, there is reason to inquire whether the surface of the earth was not, by reason of remote tectonic accidents, very different at the time when these reactions took place from what it is today. I am very happy to see that in their admirable study of the copper-mines of Butte, Messrs. Emmons and Weed have been led not only to adopt a similar hypothesis, but to give it a local geological confirmation.

Finally, I beg again to mention an idea which I have never had occasion to state heretofore except incidentally, but which seems to me to deserve more thorough study. Namely, in regions of complex fractures, with numerous systems of intersecting veins, such as those studied so minutely in Saxony, Bohemia, etc., there is doubtless reason to attribute a very important rôle to secondary phenomena of enrichment, as explaining the variations in successive fillings, which have usually been interpreted as primary phenomena, and the cause of which has been sought in a series of internal movements more or less independent, separated by long intervals of time. Perhaps, for example, the occurrence of a late deposit of highly argentiferous mineral, often accompanied with calcite and co-

balt, such as has been noted at Freiberg, Przibram, Wittichen, etc., is only the result of a simple secondary concentration. The same may be true of the cobaltiferous fillings with calcite and barite, which have been observed in sundry faults traversing the cupriferous schists of Mansfeld; and I believe that, in a general way, it is the cause of many enrichments noticed at the intersections of veins, at the junctions of cross-courses, etc., such as those described by Smith at Broken Hill and by Spurr, in the Aspen district, which, judging from the published descriptions, Mr. Weed appears to me to have interpreted very justly.

ARTHUR L. COLLINS, Telluride, Colo. (communication to the Secretary): Mining engineers owe a great deal to the suggestive papers of Messrs. Emmons and Weed—which throw much light on numberless facts in connection with ore-deposits, especially those of copper- and silver-ores.

In recent papers on this subject, no reference has been made to the remarkable copper-veins of Cornwall, which, only 60 years ago, furnished the major part of the world's copper-supply, but already seem to be almost forgotten. These deposits were described by a host of capable observers, including such men as De la Beche, Henwood and Smythe; and the separate zones of weathering, enrichment and unaltered ore which they exhibited were so strongly marked and so commercially important that one wonders that the relations of these zones were not recognized at the time.

The zone of weathering ("gossan") was often of great extent, reaching not only below present water-level, but far below the level of the neighboring sea. Thus, at Fowey Consols, the gossan extended 100 fathoms below the adit-level; and at Dolcoath "some of the earthy brown ore was found as far down as the 197-fathom level."* These gossans generally showed traces of copper; and it was recognized that they proved the former existence of sulphide-ores, from which they had been formed.

Immediately below came the great ore-bodies, such as that at Clifford Amalgamated, "16 or 18 ft. wide, of cindery copper pyrites from wall to wall;" or the "30 or 40 ft. of dredgy copper ore in the best parts of Devon Consols."†

* T. H. Collins, *Journal Royal Inst. of Cornwall*, No. 38.

† Sir W. Smythe, *Trans. Royal Geol. Soc. Cornwall*, vol. xi., part iv.

These gradually gave place to poorer ores, until, one after another, the mines were abandoned. Some 16 years ago, when one of these old-time Cornish bonanzas, the Tresavean mine, was reopened, the hard quartz ore, sparingly sprinkled with pyrite, mispickel and chalcopyrite, which was encountered, seemed to justify fully its former abandonment. The recognition of the essentially superficial origin of rich copper sulphide ore-bodies of this type will be discouraging in many cases. But it only confirms an opinion long held, on other grounds, by mining engineers.

It is noteworthy that the reaction mainly relied upon for the removal of copper from the zone of weathering, namely, the decomposition of copper sulphides by ferric sulphate, is (or was, many years ago, when I was familiar with the district) employed at Rio Tinto on a very large scale in the commercial treatment of copper-ore. The liquors from the lixiviation of heap-roasted ore were run over "raw" fine ore—originally (as I recollect) to lessen the consumption of iron in the precipitating-tanks, and to secure a cleaner precipitate. But this was found to be also an efficient method of extracting part of the copper-contents of raw pyrites. And great heaps of mixed "raw fines," and lixiviated roasted ore, aggregating millions of tons, gradually giving up their copper in solution, largely by means of this reaction, became a feature of the Rio Tinto landscape.

The supposed reaction for the re-precipitation of copper in secondary copper-ores, from cupric sulphate solutions by pyrites, can hardly take place under these conditions—it would upset the commercial process.

The evidence of secondary enrichment in gold- and silver-veins is less striking than in copper-deposits. As to gold in particular, we are accustomed to look for far higher values in the oxidized surface-ores than in the sulphides immediately beneath. This may be due as much to the ease with which gold is precipitated from its solutions as to its original insolubility; for the native gold in oxidized ores often has every appearance of secondary deposition.

As to the Smuggler-Union workings (of which I am at present in charge), a personal examination might give Mr. Emmons reason to doubt the suggestion that the richer silver-

minerals have been re-concentrated into a more recent foot-wall streak. Nor does any such streak remain unaffected by the faulting at the Pandora crossing, so far as our workings show. The great changes in the Smuggler-Union vein with depth seem rather to coincide with the changing strata through which it passes.

More striking cases might, I think, be found in the Silver Plume district of Clear Creek county, Colo., where the rich silver-minerals of the upper parts of the veins have given place to low-grade galena and ferruginous blende in depth, without any corresponding change in the enclosing rocks or gangue-minerals.

S. F. EMMONS, Washington, D. C. (communication to the Secretary): What Mr. Collins tells us about facts in the veins of Cornwall that suggest secondary sulphide-enrichment is highly interesting; and I am free to confess that I have not studied the literature of that region as fully as I should have done. Nevertheless, even if it had been as familiar to me as it is to Mr. Collins, I should probably have hesitated to draw theoretical conclusions without having seen the mines myself; for the personal equation and the point of view of the observer play, perhaps, a larger part in the study of ore-deposits than in that of any other natural phenomena. One important purpose of my paper, and its publication at the time of the Washington meeting, was to call forth remarks from other geologists upon deposits with which they were personally familiar, or to lead them to re-examine such deposits with the idea of secondary enrichment in mind.

Mr. Collins's remarks on Rio Tinto, which he has the advantage of personally knowing, are also interesting. With regard, however, to his suggestion—advanced as an apparent argument against our theory—that the re-precipitation of copper from cupric sulphate solution by pyrite can hardly take place there, since it would upset the commercial process, I would remark that, while he is undoubtedly right as to the fact, it does not militate against the reduction and re-precipitation of cupric sulphate in veins; since on the surface, as at Rio Tinto, there is free access of air, and consequently an excess of ferric sulphate, whereas in depth the ferric sulphate would have been

mostly reduced to ferrous sulphate, and (there being no excess of acid to hold it in solution) the small amount of copper in the presence of an excess of iron sulphide would be precipitated either as sulphide or as native copper.

To Professor Vogt's analogous remarks, that in his experience sulphuric acid is formed only in subordinate amount in the attack of sulphides by ferric sulphate, I would say that Dr. Stokes's experiments, made in the laboratory of the U. S. Geological Survey expressly with a view to determining the effects of the attack of ferric sulphate on various sulphides, have conclusively demonstrated that sulphuric acid is formed in all such attacks in very considerable amount; much more than he had thought possible *a priori.*

It is highly gratifying that Professor Vogt has been willing to give us so fully his views on the relation between eruptive processes and ore-deposition, a subject of which he has made a most profound study. His views and those of Prof. Van Hise may be considered to express the opposite poles of geologic opinion; the extreme views of the European and American geologists respectively on this subject—though, among the latter, Prof. Kemp leans more to the European side. To me it seems that a distinction may be drawn between the working geologists, to which class most of the Americans belong, and the professors in universities, which include most of our European *confrères.* The former are more apt to work out theories by practical testing in the mines themselves, while the latter are more dependent upon the literature of the subject, and therefore upon the study of phenomena at second-hand, from the description given by others. Thus, Prof. Vogt instances the copper-mines of Butte and of Cornwall as attributable to magmatic* extraction. In the former case he very likely based his views on my early suggestion (1886) of a genetic connection between ore-deposition and the rhyolitic eruption of the "Big Butte"; but the more detailed studies which I have made since† have shown that the deposits are earlier than the rhyolitic eruption, and that the observed facts are such as to preclude pneumatolytic action as the source of the ore in its present condition.

* I think the use of the term "magmatic" in this connection very unfortunate. I presume he refers to the pneumatolytic method of extracting the metallic minerals from igneous magmas.

† *U. S. Geol. Surv.*, Folio 38, 1897.

As regards Cornwall, Prof. Vogt's process of reasoning is that, inasmuch as many tin-deposits have proved to be the result of magmatic (pneumatolytic) processes, and as observations in Cornwall, as well as in the *Erzgebirge*, seem to show "that there can have been no absolutely essential difference between the genesis of the cassiterite and that of the silver-lead veins," the latter are to be attributed to magmatic extraction rather than to the work of underground water. From my point of view, the reverse reasoning, namely, that underground water must have had some part in both kinds of deposition, is at least equally admissible, and more closely fits the facts of nature.

Both Prof. Vogt and Prof. Beck quote in support of the magmatic theory Hussak's studies of the gold-quartz vein of Passagem in Brazil, which the latter conceives to be an ultra-acid granitic apophyse. But both Mr. Lindgren* and myself, from a careful consideration of the facts presented by Hussak, consider that he has proved it to be a normal fissure-vein, due to the action of underground waters.

With regard to the probable pneumatolytic origin of contact-deposits, there is an essential agreement between Professor Vogt and Mr. Lindgren, as shown in the paper presented by the latter at the Richmond meeting.†

On the other hand, I fail to recognize the distinction upon which both Prof. Vogt and Prof. DeLaunay lay so much stress, namely, between older and younger gold-silver veins.

There can be no doubt of the great value of such interchanges of opinion as this discussion has called forth; and it now remains for each of us, in the cases of difference of views, to put such views to the critical test of further field-studies and see how far the respective theories are applicable to the phenomena of nature.

It seems to me that the remarks of Prof. DeLaunay, at the beginning of his contribution to this discussion, may lead to misconception with regard to his views upon what we consider the essential part of the "secondary-enrichment" idea, viz., that secondary enrichment has undoubtedly, and, indeed, in many cases demonstrably taken place below the groundwater-

* "Metasomatic Processes in Fissure-Veins," *Trans.*, xxx., 642.

† "The Character and Genesis of Certain Contact-Deposits," by W. Lindgren, p. 226 of this volume.

level. For that reason I take this opportunity to quote from his last article in the *Revue Générale des Sciences*, entitled "The Variations of Metalliferous Veins in Depth," in which he expresses himself in more definite terms. Under the caption, "Secondary Changes of Veins in Depth," after describing the two zones, *above* and *below* the groundwater-level, and the reactions that may go on there, he summarizes as follows:

"A body situated in this zone of permanent waters below this hydrostatic surface (which may have a very complicated form) finds itself in the condition of a wooden pile, which, remaining always immersed in water, suffers no change. On the other hand, above the hydrostatic surface (the groundwater-level) there is a perpetual movement of the waters, a bringing in of oxygen and carbonic acid, alternations of humidity and dryness, etc.; it is there only that are produced the secondary reactions of which there is question here, and by which all the upper parts of metalliferous deposits are thoroughly modified."

Mr. Lindgren's paper* constitutes a very valuable and very practical contribution to the literature of ore-deposits. It has long been my opinion that the usage which prevails among miners of calling so great a variety of deposits "*contact-deposits*" is bad, because the term, as thus applied, is illogical and incapable of definition; and I have advocated its restriction to such deposits as occur along the contact of eruptive and sedimentary rocks. Mr. Lindgren's usage restricts it still further, but has the great advantage that it rests on a distinctly genetic basis. During the past summer I have had opportunities of observing, though not of studying thoroughly, several deposits which, in many respects, fall within his definition, though I should have hesitated in some cases to call them contact-deposits.

Most of these deposits were seen in the Boundary district of British Columbia, in mines lying on either side of Boundary creek, near the town of Greenwood. They constitute the workable ore-bodies of many of the most important mines of the district, such as the B. C., the Knob Hill and Ironsides, the Mother Lode, and others. The ores of these mines are of very low grade, carrying on the average from 2 to 5 per cent.

---

* *Trans.*, xxxi., 225.

of copper, with a few dollars in gold per ton. They occur, however, in large bodies, and contain much lime, iron and other bases, with little sulphur, so that they can be mined and smelted at an extremely low cost. By reason of the liberal policy which the Canadian Pacific Railroad has adopted, of building spurs to all the important mines, so as to connect them with the smelting-works, it is estimated that the total cost of mining and smelting will be not over $5 or $6 per ton.

The region in which the mines occur is very well covered, either by a luxuriant forest growth or by glacial drift, often with both, so that outcrops are comparatively rare and the geological structure is correspondingly difficult to decipher. Hence, in my short visit, I was only able to determine certain very broad general outlines.

The immediate valley in which the town of Greenwood lies is carved out of a mass of light gray, coarsely crystalline granitic diorite, the longer axis of which apparently runs N. and S. with the valley. As one ascends the tributary ravines on either side, E. or W., one passes into a zone of much altered greenish rock, called by the miners "diorite," beyond which are porphyries, forming, in general, the crests of the bounding ridges. At various points within this zone are outcrops of white crystalline limestone; and it was soon found that the greater part of the so-called "diorite" is simply altered limestone, being largely composed of various normal contact-minerals, the most prominent of which, in the few specimens gathered, was actinolite. Very likely some of these altered rocks may be of eruptive origin; as interbedded tuffs and breccias were observed at the Ironsides mine, and dikes are frequently found crossing the ore-bodies. Such of the porphyries as were examined under the microscope were found to be of the syenitic lamprophyre type. They are distinctly later than the limestone, cutting it in dikes and sending apophyses into it. The general impression derived in going through the country was that they are also later than the diorite; but no contacts were found which would afford absolute proof of their relative age in this respect.

Compared with Mr. Lindgren's type of "contact-deposits," the ore-occurrences of this region show the following striking resemblances:

1. The association with typical contact-minerals, such as the amphiboles, garnet, vesuvianite, zoisite, etc., and the evidence that the ore-minerals were of nearly contemporaneous formation. Mr. Lindgren, who has kindly examined for me, under the microscope, thin sections of ore from the Mother Lode, states that "they show pretty clearly that a metasomatic replacement has occurred, during which a granular limestone has been converted into amphibolitic rock, and that simultaneously, or almost simultaneously, magnetite and sulphides have been developed."

2. The association of magnetic oxide of iron, in considerable amount, and of contemporaneous formation, with sulphides of iron and copper (more particularly the latter). This peculiar association I had never had occasion to observe until last summer.

3. The irregular manner of occurrence of the ore-bodies. Not only does the material grade off insensibly in every direction, inwards as well as outwards, from the so-called "ore" into low-grade rock, but there are no fracture-planes or walls enclosing the ore-shoots, or even defining their direction. This constitutes a very serious element of uncertainty in the mining of such deposits.

4. The ore-bodies are cut by eruptive dikes which apparently do not disturb or exert any metamorphic influence on the ore, and yet are not at all mineralized themselves; so that one is puzzled to say whether the dikes are later than the ore, or the ore later than the dikes. In the B. C. mine, for instance, three such dikes lying in a nearly horizontal position, and aggregating some 90 ft. in thickness, have been cut in sinking a vertical shaft 250 ft. through the ore-shoot.

On the other hand, the definition of a contact-deposit as involving a close proximity with an eruptive body cannot be regarded at present as strictly applicable to these ore-bodies. The belts of metamorphosed limestone appear to be from one to two or more miles wide; and it is not proved, as yet, that there are considerable eruptive bodies in close proximity with the respective ore-shoots. The final settlement of this question must, however, await a detailed geological survey of the region.

Another probable instance of contact-deposits is seen on the

west slope of the Grampian hills, opposite the Horn-Silver mine, in Utah. Here a monzonite intrusion has broken through the dolomitic limestone; and, along the contact, there is a zone from a quarter- to a half-mile wide on the surface (the actual thickness may of course be very much less, dependent on the slope of the contact) of a reddish-brown rock, made up largely of garnet, in which, associated with veins of remarkably beautiful fibrous white tremolite, are deposits of copper-, lead- and zinc-ores, the following of which has been found by the miners to be a very difficult and discouraging matter. I was unable to enter any of the mines, and therefore cannot speak of the manner of occurrence of the ore further than to say that it presents the peculiar association of magnetite and contact-minerals with sulphides, mentioned above.

Walter Harvey Weed, Washington, D. C. (communication to the Secretary): Prof. Vogt has placed us all under obligations by presenting this summary* of the views he has expressed in his various papers during many years past. As a leading exponent of the theory of the igneous origin of certain ores, he commands the highest respect; and it is with considerable hesitancy that I venture to offer a friendly criticism of his views.

The direct igneous origin of certain iron-, nickel- and copper-deposits of Sweden, as differentiation-products of cooling igneous magmas, is generally accepted. Personally, I am too familiar with cases of extreme differentiation in igneous rocks to doubt the probability of such an origin. In his treatment of gold- and silver-veins, however, Prof. Vogt is less satisfactory. Indeed, he admits its weakness in summing up his case. The well-known association of almost all gold- and silver-ore, and of many silver-lead, deposits with igneous rocks suggested long ago that the connection was a genetic one, and, in fact, was the basis of the now defunct lateral-secretion theory. Yet in a majority of cases the proof is clear that the deposits, as they now exist, are the work of water, and therefore are neither of direct igneous origin nor of the indirect or pneumatolytic origin, in which gases and vapors, not simple heated water, brought the material to its place. Van Hise has called the

* *Trans.*, xxxi., 125.

latter circulating meteoric water, as in some instances it undoubtedly was. Yet it is difficult to draw the line. As I have shown elsewhere, the hot springs and geysers of the Yellowstone Park are largely due to ordinary surface-rainfall, percolating downward through the earth's crust to the still-hot lavas beneath.

In my judgment, not only do the igneous rocks offer the most favorable source of the metals, as indicated by many observers, but the intrusive igneous rocks furnished the "dynamic" force, fissuring the adjacent rocks, and starting new circulations of water and vapors that are independent of normal groundwater circulation, as has been so ably stated by Prof. Kemp. Quite as important is the changed physical condition due to the intrusion. The strains and stresses due to the forcing of a large body of magmas into the solid crust of the earth are only a part of this effect. As a result of extreme heating followed by cooling, new fractures originate in the adjacent rocks; shear-planes and joints form in the cooling igneous mass; the differential shrinkage of dike- and wall-rocks leaves contact-fissures; breccias are formed of shattered country-rock along igneous contacts; and all these actual or potential fractures are planes of weakness, sought out by later movements and opened into fissures, or simply directing and guiding the circulating waters by furnishing an impervious cover.

Concerning the source of the metals, the veins of Butte, Granite mountain, Marysville and Elkhorn, Montana, as well as many Mexican examples studied by the writer, show that the occurrence of the veins at or near the border of granitic or dioritic rocks is of prime importance. In some instances, basic differentiations of the rocks are exposed, and, being richest in metals, are the most likely source; but such basic masses may be deep-seated and not exposed by erosion. In these deposits there is often the clearest possible evidence of vein-formation by circulating waters, and none whatever of pneumatolytic activity.

The "blown-in" ores of Prof. Vogt can be explained by the porosity of the altered rocks, due to baking. His theory concerning them interests me; for it implies that the "blowing-in" of the ore preceded the eruption or proceeded from the fused rock. Possibly the porosity of the altered contact-rocks

afforded an outlet for vapors squeezed out of the cooling magmas. In that case, the ore might correspond to a pegmatite. The ore of the Dolcoath mine at Elkhorn, Mont., consists of native gold and tetradymite in a porous garnet-calcite rock, shown by a study of thin sections to be an altered, impure limestone, made porous by the baking and recrystallization of the mass. At Marysville, Mont., where the ores are unquestionably of aqueous origin, sulphides occur in diorite and slates alike.

The conclusion of Prof. Vogt* concerning certain Norwegian pyrite-deposits, that "their genetic relation to the eruptives is indisputable," rests upon the facts that 27 of the 28 lie very near, or actually within, regions of compressed gabbro, and that they are, moreover, independent of the age of the enclosing slates. This does not seem to me entirely and comprehensively conclusive. Some of the deposits occur in shear-planes in the eruptives; they are cut by apophyses; and they are compressed by mountain-folding. Of these arguments the most important is the occurrence of the ore in shear-planes of the eruptive gabbro. The others fit the theory of pre-gabbro deposition, according to which the gabbro was sheared, and apophyses were sent out, before the deeper parts of the mass had cooled.

He says† that, for the older as well as the younger series of veins, a clear genetic connection with eruptive rocks can be established. This is a broad assertion, not proved beyond reasonable doubt by the facts so far presented. It is indeed suspected that there is a constant association which is significant; but a genetic connection is as yet merely a hypothesis. My own belief is simply that the eruptive rocks have furnished the material from which heated (or cold) waters have gathered the material to form veins.

I have attempted, moreover, to emphasize the fact that many ore-deposits are the ultimate results of different periods of "mineralization." As long as an ore-deposit was regarded as the product at one period, of a single act, so to speak (as some deposits probably are), it was impossible to reconcile certain inconsistent features, or explain them by any theory of either

* *Trans.*, xxxi., 141.

† *Trans.*, xxxi., 145.

lateral secretion or ascending solutions. Once it is understood that an already-formed vein or deposit has been subjected to changing water-levels, as the result of elevation and depression or climatic change, and that faulting may have introduced later solutions from below, it is easy to account for the varied conditions observed in many mines.

The most important single point brought out in Prof. Vogt's paper is, in my opinion, the precipitation of sulphides from solutions by leaner unaltered sulphides. Prof. Beck's remarks upon the rich *bonanzas* make clear what other published accounts have left in doubt. My own papers have attached great importance to the reaction between sulphide-ores and solutions holding metallic sulphates; that is to say, I know that existing sulphide-ores cause the precipitation of rich metallic sulphides by reaction with the solutions. That those solutions *may* come from below, I have myself declared; that in very many cases they come from above is, I believe, proved by the facts I have submitted, as well as by the evidence of a large number of observers.

Charles R. Keyes, Des Moines, Iowa (communication to the Secretary): We are certainly deeply indebted to Mr. Lindgren* for so excellent a review of the subject of molecular interchanges associated with the production of ore-bodies occupying fissures. The importance of considering the changes of the wall-rocks of ore-veins has certainly never been adequately recognized. Lying, as it does, in no-man's land, between the territory of the miner and the province of the petrographer, the subject has been sadly neglected by both, instead of being made mutually productive.

While there is, no doubt, great need of an agreed technical terminology to express the multifarious conceptions and the various shades of meaning, I very much question the wisdom of even attempting to adapt, at least in its entirety, the petrographical nomenclature, already well established, to the recognized phases of ore-formation, where processes are not so well understood, and exact terminology must necessarily remain for some time yet indefinite.

The meaning commonly ascribed to metasomatism, when

* *Trans.*, xxx., p. 578.

applied to ore-deposits, seems somewhat unhappily chosen. We sometimes get a clearer insight into things by referring to them under older and entirely different names. The title metasomatism as used by Mr. Lindgren is, I take it, almost, if not exactly, co-extensive with the somewhat older term of mineralogical metamorphism. The latter term has been widely used by petrographers generally, and has come to have a special significance in connection with the microscopic study of rock-masses.

So far as ore-deposits are concerned, these two terms may be, without serious impropriety, regarded as identical and interchangeable. But the fact should not be lost sight of, that besides strictly metasomatic change, there are other grand groups of molecular changes among which may be mentioned, in particular, paramorphic change. The latter, while it may have no immediate connection with ore-deposits, has an extremely interesting mineralogical rôle, which cannot well be overlooked, and which greatly elucidates some of the broader phases of rock-metamorphism.

As generally used by writers on ore-deposits, the term metasomatism does not signify a simple or definite process, or an assemblage of distinct processes. It is merely a vague title given to an indeterminate group of ordinary chemical activities, in which the only essential feature which the idea carries is that each chemical change is definitely located in space. Among ores it has special emphasis, for the reason that chemical substitution takes place with the desired stationary residuum. Emmons succinctly states the vagueness of the problem when he says that interchange of substance is "not necessarily molecule by molecule," but "in such manner as to preserve the original structure, form, or volume of the substance replaced."

To illustrate more clearly for present purposes, we may fancy a point of limestone bathed by a stream of moving, mineral-laden water. If the limestone substance is gradually carried away we have simple solution; if from out the stream mineral matter is left upon the limestone, we may have simple precipitation or incrustation; but if, as the molecules of limestone are dissolved, new molecules immediately take their places, we have substitution or replacement. This last, however, is not necessarily metasomatism, as I understand it.

To the student of the general metamorphism of rock-masses, metasomatism is a sharply defined chemical process by which, in the solid rock, usually, mineralogical transformation goes on. At least four well-marked phases are readily distinguished. A characteristic molecule may break up into two or more, with little or no addition or substitution of extraneous elements. Or, there may be reactions between adjoining crystals or substances. Or, thirdly, some of the elements entering into the composition of the new minerals may be brought in from a distance. A fourth phase may occur when a foreign substance entirely displaces a component, molecule by molecule. There are still other distinctions to which reference might be made, but it is not necessary at this time.

In all of these cases, the interchanges are assumed to take place in the rock-mass with no aid from circulatory waters other than those which may move through the ordinary micro-capillary pores of the stone.

In the mineralogical metamorphism of a rock-mass in a region undergoing dynamic compression, such as is initiated by mountain-making forces, the so-called circulatory underground waters are only of secondary importance. The fissures through which these waters pass are relatively local in influence; and changes that may take place along their walls may be regarded as affecting only a very small part of the rock-mass itself.

As thus understood, it is doubtful whether ore-deposits of any considerable extent are ever really formed through true metasomatic action. The conditions under which chemical change goes on in and immediately about cavities in rocks are so different from those under which the mineralogical changes in the rock itself take place that it appears inadvisable to attempt to extend the definition of a term already well established in microscopical petrography, and thereby to do away with its usefulness altogether.

Mr. Lindgren himself, I think, recognizes the force of this factor when he specifically calls attention to the wholly distinct character of the alteration taking place in the body of the rock-mass (to certain phases of which I have considered the term metasomatism restricted) from that of the change or replacement occurring in fissures, and says, " the metasomatic

processes in wall-rocks of the fissure-veins differ generally from those of regional (static and dynamic) metamorphism."

The restricted petrographical idea of metasomatism is, no doubt, very attractive for application to ore-deposits. But the already widely-used term replacement seems to cover more fully and more appropriately the analogous phases, as exhibited by the ores.

The main usefulness of the idea of metasomatism, as applied to ore-bodies, is to give rise to a great taxonomic group of deposits which are formed often where no previous cavities existed, and hence to set these off, geologically and genetically, from all other classes of ore-formations.

It is important to note, in this connection, that the period of maximum activity in the mineralogical change of rock-masses does not often coincide with the period of maximum ore-formation. As a rule, the latter is long subsequent to the former, and is the immediate outcome of activities and conditions wholly distinct.

In its more extended signification, the term metasomatism is not very far from meaning practically the same as chemical change, at least so far as ore-deposits are concerned. In the sense intended by Mr. Lindgren, replacement appears to meet most nearly the requirements imposed by the conditions presented by the ore-deposits. The exact group of chemical processes involved, and the definite set of conditions existing in each particular case, are not what are first sought in ore-exploitation. The usefulness of the distinction is really inversely proportional to its success in avoiding expression of exact values.

In metasomatism proper, as a mode of rock-alteration due to static or dynamic metamorphism, there are recognized a number of distinct phases, the results of varying physical conditions and differences in chemical composition and mineralogical constitution. Such are uralization, sericitization, saussuritization, epidotization, etc. The suggestion of analogous alterations due to contact-metamorphism, or in connection with fissure-veins, does not appear to serve a similar useful purpose; and in the special case of ore-replacement in veins the central idea is completely lost. Topazization, tourmalinization, scapolitization, fluoritization, and the like, do not, to my mind, pre-

sent practical features for the classification of ore-veins, or features which can be made use of in ore-exploitation.

PROF. FRANK D. ADAMS, McGill University, Montreal, Canada (communication to the Secretary): Mr. Lindgren's paper* is a valuable contribution to the literature of ore-deposits, bringing together as it does a great number of facts concerning the metasomatic changes developed by vein-forming solutions in the rocks which they traverse. It is also of much interest as an attempt to classify mineral veins according to the character of the metasomatic changes which accompanied their development, and especially according to some *predominant* metasomatic mineral, which they contain. This principle, however, as Mr. Lindgren remarks, seems to have serious limitations when adopted for purposes of classification—one of these being the fact that the same waters may give rise to different metasomatic minerals in the case of different rocks.

Furthermore, just as the various magmas with which Mr. Lindgren considers the various kinds of vein-making solutions to be severally connected pass into one another by imperceptible gradations, so do these solutions also; and thus, instead of a series of well-defined classes of mineral veins, an almost continuous series will be met with in nature. This difficulty, however, is shared by all systems of petrographical classification, and by most of the other systems proposed for the classification of mineral veins.

In the case of the cassiterite-veins (Mr. Lindgren's Class I.), for instance, the *predominant* metasomatic mineral is said to be topaz; but in the most extensive deposits of this class which are known—those of Cornwall—the predominant metasomatic mineral would appear rather to be tourmaline.

In the apatite-veins (Class II.), scapolite is taken as the predominant metasomatic mineral. This is true of the Norwegian deposits; but in the Canadian deposits, which are even more extensive, while this mineral is very common, it cannot be considered as *predominant.* These Canadian deposits, while in many cases at least occurring in association with basic igneous rocks, as in Norway, are usually found, not in contraction-joints of the intrusive itself, but as veins cutting the lime-

* *Trans.*, xxx., p. 578.

stones and associated rocks of the Laurentian, which are penetrated by these intrusives. The apatite, unlike that of Norway, is a fluor-apatite, not a chlor-apatite; and the predominant metasomatic mineral is malacolite. So notably is this the case that the prospectors in the apatite-districts always look for "pyroxene," and regard it as an almost certain indication of phosphate in the vicinity. Next in abundance to the malacolite is, perhaps, mica (phlogopite and biotite), which in some cases is present in such large amount that apatite-mines which were abandoned on account of the fall in price of that mineral in the years 1893–94 have been, by reason of the more recent demand for phlogopite, opened up and worked anew for this latter mineral. While, therefore, the Norwegian and the Canadian apatite-occurrences undoubtedly belong to the same class of deposits, the former is characterized by the presence of chlorine minerals, while in the latter this element is largely replaced by fluorine, which is also so commonly found in association with cassiterite-veins. The chlorine-bearing scapolite thus cannot be considered in all cases as the *predominant* metasomatic mineral required by the definition of Class II.

Mr. Lindgren's views concerning the close genetic association of most mineral veins with igneous masses seem to be abundantly supported by the facts, as also his conclusions with regard to the preponderating influence of pneumatolytic action in the case of the cassiterite- and apatite-veins, as shown by the constant association of chlorine-, fluorine-, boron-, phosphorous-, titanium- and lithium-minerals with them.

Specifications for Steel Rails.

Discussion of the Paper of Mr. W. R. Webster, Containing Specifications Proposed by the American Branch of Committee No. 1 of the International Association for Testing Materials* (see p. 449).

R. Trimble, Pittsburg, Pa.† (communication to the Secretary): There are in the proposed specifications only two points on which I wish to comment at this time.

---

* To this discussion belongs also the paper of Mr. R. W. Hunt, on "The Finishing-Temperature of Steel Rails," presented at the same meeting (see p. 458).

† Principal Assistant Engineer, Pennsylvania Lines West of Pittsburg.

1. Paragraph 6, relating to *Section*, reads: "Unless otherwise specified, the section of rail shall be the American standard, recommended by the American Society of Civil Engineers." I would omit the words "unless otherwise specified," making it read, "The section shall be the American standard," etc. Recent reports indicate a wide use of the American Society sections; and, so far as we are able to judge at the present time, these sections are giving good service, and are satisfactory to all parties. It seems to me that in preparing a standard specification we should adhere, as far as possible, to one standard section. We should make the specification exactly as we want it, and endeavor to convert as many as possible to what we believe to be the best practice.

2. Paragraph 8, relating to *Length*, says: "The standard length of rails shall be 30 ft." To this provision the writer is opposed. Most of us can remember when 28 ft. was the standard length of a rail. This length of 28 ft., and that of 30 ft., which came later, were fixed simply by the length of the cars employed in transporting the rails. But we now have cars from 33 to 38 ft. long (inside dimensions); in my judgment, the shortest car now built for such purposes will accommodate a rail 33 ft. long; and therefore the minimum standard length should not be less than 33 ft. A number of roads are using rails of this length, which has the very great advantage of doing away with 10 per cent. of the joints—the joint being one of the weak spots in our present arrangement of track.

E. C. Potter, Chicago, Ill. (communication to the Secretary): I have been so long out of touch with practice in the manufacture of steel rails that I hardly feel myself competent to discuss in detail the proposed American specifications, which must necessarily be more or less intimately related with present technical and commercial conditions. Since it is reported, however, that these specifications are declared by some to be too favorable to the manufacturer, I may say frankly that I do not think such a criticism valid, since rails made according to them will, in my judgment, give good service. Mr. Hunt's specifications, proposed in 1895* for heavy sections, manufactured west of the Alleghanies (that is, from the ores available in that region),

* *Trans.*, xxv., 653.

draw the lines a little closer, chemically, as to carbon, phosphorus and silicon; but I do not believe they would result in better rails.

I think that, in the region supplied with Lake Superior ores, it will soon be, if it be not already, impossible to keep the phosphorus in steel rails below 0.085 per cent.—Mr. Hunt's limit—which, I think, may be safely raised to 0.10 per cent.—the American Committe's limit. In recent years, I have grown to be a believer in the value of silicon in steel, having seen it demonstrated many times, to my entire satisfaction. I should be willing to see the maximum silicon-limit put higher than that of 0.20 per cent., set by the Committee; and I believe that the change would be beneficial to the rail.

However, I am not disposed to place too much reliance upon chemical composition, or to quarrel seriously with minute differences in limits proposed under that head. I believe that the principal source of the unsatisfactory wear of rails is the treatment of the steel in the rail-mill, and that the quality of the future service of a rail may be made or marred right there. The treatment in the heating-furnace and the temperature of rolling and of finishing have more to do with the wearing-qualities of rails than decimal fractions in chemical composition. But these important factors cannot well be defined in specifications.

The specifications proposed by the American Committee seem to me to be fair and reasonable; and I think that, so far as they control the manufacture, they tend towards the production of good rails.

George B. Woodworth, Chicago, Ill.* (communication to the Secretary): This company does not prescribe any specifications for rails, beyond the requirement of good mechanical workmanship, but takes them upon the usual guaranty of five years' service. This is not an entirely satisfactory way of dealing with manufacturers; yet, as a matter of fact, we have been receiving for the last five years, all things considered, rails of better quality than ever before.

The specifications of the American Committee seem to be all right. So far as mechanical inspection is concerned, they em-

* Inspector of Rails, Chicago, Milwaukee and St. Paul Ry. Co.

body substantially our practice. Two points, however, which are now receiving considerable attention, and the incorporation of which in standard specifications might be considered with advantage, are the increase of the work done in the reduction of blooms to rails, and the lowering of the temperature at which it should be done, especially at the finishing-pass. These improvements, I suppose, might encounter considerable opposition from the rail-makers, because of their probable effect in limiting the rate of output.

In this connection, I may say that during the last three years we have re-rolled and re-laid in the track about 40,000 tons of heavy rails, which had been replaced upon their removal by still heavier sections. The section of the re-rolled rails is about 10 per cent. lighter than their original section. We are expecting good results from these re-rolled rails; but it is yet too early to form a conclusive judgment.

W. R. Webster, Philadelphia, Pa.: The analyses and tests referred to by Sir Lowthian Bell as comprising material from which he "could prove, and disprove, everything that could be said for or against any composition of a rail," are, no doubt, similar to those embraced in many of the records which we have in this country. The fact that the chemical composition of some of the rails is not in accord with the physical tests could be accounted for in many cases, if we had a full history of the manufacture of the blows of steel in question. In other words, the heat-treatment of the steel has not been recorded; and the chemical composition alone will not account for all the differences in results observed in the tests made or in the behavior of the rails in use. For instance, a rail of inferior chemical composition, finished in rolling at the proper temperature, will give better results than a rail of good chemical composition, finished in rolling at too high a temperature. Again, two rails of equally good chemical composition, one high, and the other low, in carbon, but both finished in rolling at the same temperature, may give very different results in service, or under the drop-test. If the finishing-temperature was right for the low-carbon rail, it may have been too high for the high-carbon steel, and thus may have given in that case a poor rail.

Notwithstanding these differences, all will agree that, to make the safest and most durable rail, we must start with a uniform steel of good chemical composition, and roll it under the proper conditions of heating, reduction and finishing-temperature.

The section of the rail has a direct bearing on the finishing-temperature, because the large mass of metal in the head carries the heat much longer than the thinner flanges and web. I have for some time past advocated putting more metal in the flanges and web of our heavy rails, in order to retain the heat, and allow the work of rolling to be done on the head at a temperature low enough to break up the coarse grain, and produce a tough structure.

Another important point to be considered is the proper amount of carbon required in rails of different sections to produce the best results. It is generally admitted that steel containing a moderate amount of carbon, and receiving enough mechanical work at a low temperature to produce toughness and hardness, will give better results than higher-carbon steel, finished in rolling at a higher temperature. The latter method is often used, without fully appreciating the trouble which may follow as a consequence. With increase of carbon, the danger of producing a large grain in the steel by finishing at a high temperature is greatly augmented. This fact, in connection with the large mass of metal in the head, and the much smaller mass in the thin flanges and web, makes the manufacture a difficult one; and it is not surprising that rails rolled under these conditions do not always give satisfactory results.

Again, it is important to have a satisfactory check on the finishing-temperature of the rails. It is not of much use to say that the rails must be finished at a "dull red" or any other particular color. Opinions may differ as to the exact hue of "dull red;" and in the day-time it certainly looks very different from the way it looks at night. The best check we have, I think, is a simple one which I have advocated for some time, namely, the amount of shrinkage that takes place in a 30-ft. rail from the time it is cut by the hot-saw until it has cooled to the normal atmospheric temperature. Just how many inches it is proper to allow can be easily decided by experiment, and introduced into the specifications.

The structure produced by too high a finishing-temperature

is not thoroughly understood; and the drop-test has not been recognized as the most important check upon it which we possess. This test is somewhat crude in one sense; but in another respect it is more valuable than a tension-test, particularly on material that has been finished at too high a temperature in rolling. A drop- or shock-test will develop brittleness in cases where a fair elongation may be given under the slow pull on the testing-machine. In my judgment, a drop-test should be made on every blow of steel, since it is the most satisfactory test we have for determining the quality of the finished rail, and will expose brittleness, due either to inferior chemical composition or to improper heat-treatment.

The Carnegie Steel Co., by their new method of rolling, are finishing their rails at a lower temperature than formerly, and are getting better results from the same section of rail with steel of the same chemical composition.

Some years ago, investigators of the relations between the chemical composition and the physical properties of soft steel became discouraged, and gave the problem up, because the results were so conflicting. This problem is now better understood; allowances are made in the physical requirements for material rolled into different thicknesses; and the finishing-temperature is carefully controlled. From the chemical composition of the steel, the tensile strength of the finished product is predicted; and the steel is rolled into finished forms without losing the initial casting-temperature. With regard to rail-steel, we have the same problem before us, only in some respects more difficult, by reason of the sections to be rolled and the higher-carbon steel to be used.

I would propose for further discussion the points above mentioned, namely:

1. The advantages to be gained by using more metal in the flanges and web of the heavier sections of rails.

2. The advantages and disadvantages of using a higher-carbon steel than that called for in the specifications under consideration in this discussion.

3. The amount of shrinkage in a 30-ft. rail, to be specified as an accurate check on the finishing-temperature in rolling.

4. The advisability of requiring a drop-test on each blow of steel.

I appreciate that it is not only the finishing-temperature which must be considered, but that sufficient work must be put on the steel at a temperature low enough to break up the coarse structure and produce the tough steel desired. This is recognized by some who are rolling rails direct from the ingot; and they claim that better results are produced by this method than by re-heating the bloom. This might be considered another point for discussion.

P. H. Dudley, New York City (communication to the Secretary): I heartily concur in the opinion expressed to me by our Secretary that "this subject is one of the most important, both technically and commercially, which can engage the attention of the engineer and metallurgist," and I wish to add, also, the railway official and the financier. Many financial men now thoroughly understand that the physical condition of a railroad must be first-class to secure earnings from present rates.

The section of a steel rail in itself seems a small thing, hardly needing attention, much less study. But when it is considered what steel rails in thousands of miles of track must do to carry the high-speed passenger-trains and the heavy freight-trains safely and economically, the steel rail becomes a matter of first importance.

The form of the section, the distribution of the metal, and the physical properties of the latter to resist wear and at the same time perform the functions of continuous girders on flexible supports, have all received attention and study, and will continue to do so as long as any progress is to be made in railway-transportation.

Transportation is a commercial service which railroad companies or systems have to sell; and a part of the great progress which has been made in the United States is due to the striving of each company or system to improve its service, so that it may attract more patronage and obtain greater commercial results.

Some railroad companies have improved their service by introducing stiffer rails of higher physical properties than those in general use, thus reducing the undulations of the permanent way, and producing smoother-riding tracks and less train-resistance.

As a consequence, faster trains were inaugurated, stimulating the competition of the principal railway systems of the world. Heavier coaches and locomotives for passenger-service followed, as well as heavier freight-trains—all rendered possible by the reduced train-resistance on the smoother tracks. Freight-rates per ton-mile which would not have covered the cost of operating on the poor tracks, returned a profit on the smoother rails.

The railroad companies which deemed it necessary, a few years ago, to improve their service by the use of rails of higher physical properties, assumed the entire responsibility as to the wear and breakage of such rails. The manufacturers were not asked by the railway companies to guarantee the quality of the rails made according to the compositions and methods specified.

Experience with rails of high physical properties has shown the wear of the entire surface of the rail to have been made so uniform that, after ten years, the condition of the track was nearly as good as when the rails were comparatively new. The joints were alternate, of the three-tie type; and the receiving-ends of the rails did not wear more than other portions.

Not only to reduce the train-resistance to a low limit, but also to be able to hold it there for a number of years, during the life of the rails, is a matter of the utmost importance to the railway-interests.

I am not aware that better, or as good results, have been obtained in this country or abroad under modern traffic on rails of the usual physical properties.

The physical properties of the metal of the rails and the distribution of metal in the sections are now known to influence directly the cost of maintenance of the permanent way; the standard of track which can be obtained; the wear and tear of the equipment; the combined stability of the moving trains and track; the magnitude and safety of the traffic and the economy of operating.

The functions of the metal and the rail-sections made therefrom are physically and commercially more diversified than is the case with metal for bridges. For the latter there is a consensus of opinion as to what the physical properties should be. In bridges, the working-strains can be calculated, and provision

made, by the use of sufficient material, for factors of safety of 5 or 6.

The strains in rails under moving trains have not as yet yielded to mathematical analysis, though they have long been known to be much higher than those considered permissible in bridges where the strain of the weight of the structure must be sustained as long as the bridge is in service, while the strains of moving loads will last for some seconds, to some minutes (for slow trains held by signals). In rails under moving trains the duration of the greatest intensity of the fiber-strains per linear inch is but a fraction of a second for each individual wheel-load; and before the following wheel reaches the same portion of the rail, the strain has been not only relieved but followed by a strain of an opposite character.

Strains in rails under moving trains have been measured for speeds under 50 miles per hour and found high, as had been expected, particularly where great tractive power was exerted to draw the train.

That "sets" in rails having only from 35,000 to 45,000 lbs. elastic limits frequently take place in the track, can be readily understood from the measured fiber-strains obtained.* Fiber-strains as great as those which occur a few times daily in rails under running locomotives would not, nor could, be permitted in any other structure of importance.

The British Specifications.

Mr. Webster quotes from the report of May, 1900, of the committee of the British Board of Trade, the following:

> "The evidence before the committee indicated what the limiting proportions of carbon, sulphur, phosphorus, manganese and silicon should be. As regards the influence of phosphorus, it is pointed out that, in the broad sense, brittleness of steel does not depend upon the total amount of phosphorus present, as that element may exist in steel in at least two different forms, one of which is comparatively innocuous."

As regards the limiting proportions of carbon, silicon, phosphorus and manganese, opinions differ, as also do the results obtained in practice. It may be said of carbon (as the com-

* The results are usually reported in fiber-stresses in pounds, which are set up by the strains per square inch in the extreme fibers of the base of the rails.

mittee says of phosphorus) that whether the structure of the metal obtained will be tough or brittle depends upon the form, as well as the quantity, of the carbon in the rails.

With the extensive knowledge now prevalent in regard to the effects of mechanical and heat-treatment upon steel for rails, a range of physical properties can be obtained from the same composition, so that even much higher carbons than those given in the proposed specifications, but with lower phosphorus, will produce a metal of great tenacity. The writer has not had any serious difficulty in obtaining, in suitable rail-sections, a tough metal of 55,000 to 60,000 lbs. elastic limit and 12 to 16 per cent. elongation per inch, in the base of the rails, when tested upon the side under the drop.

In regard to phosphorus, the writer has not been so fortunate as to find a part of it "innocuous" in the rail, as a general rule. Rails having 0.08 to 0.10 per cent. have broken more frequently in the track than those having only from 0.05 to 0.06 per cent. Our makers may not be able to render the phosphorus "innocuous in one form," and it is to be doubted whether the English practice in that respect is any better; for many English rails have broken in the track under our heavy traffic. Many years ago, when the question of increasing the speed of trains came up, the writer considered, from the experience in the track with many rails ranging from 0.08 to 0.10 in phosphorus, that it would be best to reduce the phosphorus to a lower limit and increase the carbon, and in this way make a tougher and safer rail.

To test the rails, the writer revived the use of the drop-test, which had then become practically obsolete; and, by experimenting for a short time, was able to produce a rail of higher-carbon steel, which was remarkably tough, standing 4 to 6 blows of the 2000-lb. tup dropping 25 or 30 ft.

One of the important facts found by increasing the toughness of the rail was, that instead of a brittle fracture, which would break from the base up through the head, the law of fracture of the tough rails was that the base would break as an entire member of the section, then the fracture would rise above the neutral surface, and, by the further bending of the head, force out one or two pieces from the broken base of the rail, the head finally fracturing as an independent member. The curvature

of the head was usually about twice as great as the curvature of the base.

As already indicated, the result has been a marked reduction in the number of fractures in the track, as compared with those of former compositions of higher phosphorus and lower carbon, under the same traffic.

The chemical specifications for proposed English rails are given as though the conditions of traffic were similar to those in the United States. Very few passenger-locomotives in England carry as heavy axle-loads as are carried in the United States. The coaches are all smaller; and the majority of them are of the short 4-wheel type, about 32 ft. in length. The wheel-loads are light, and the wear on their rails—which are rolled at a low heat—is similar to that which occurred on our rails with the light wheel-loads of 25 years ago. The volume of traffic is large; but with the light wheel-loads the rate of wear is small.

The weight of the English passenger-trains is from 200 to 300 (in a few instances reaching 400) tons, while the mineral- and goods-trains range only from 300 to 400 (in a few instances 500) tons. Their goods-wagons are all small, carrying from 6 to 7 tons, while their coal- and mineral-wagons carry 10 tons. The coal-wagons are not all owned by the railroads, some 500,000 belonging to the private coal-companies. They are all small.

The intensities of the wheel-pressures per unit-area are smaller than those which occur in the United States. The tractive power exerted to draw these light trains is also smaller than is required in the United States for the heavy trains. Finally, the freight-rates are two and three times as high as in the United States.

On the continent of Europe, where the international testing-committee originated, the wheel-loads are also light. The weights upon the locomotive-drivers are limited, as a rule, to 14 tons, while in each locomotive there is a speed-indicator, with a tablet, limiting the speed which it can run light or when drawing a train. The speeds are all slower than those necessary for many of the regular trains in the United States.

In this country, containing over 40 per cent. of the entire railway mileage of the world, the companies have not made any such limitations as the loads upon the drivers or the loads

upon the car-wheels, and we need rails of higher physical properties than are required for the traffic abroad. The locomotive has been doubled in weight and tractive power, and the speed of passenger-trains was increased to a marked extent, while the loads drawn by passenger-engines have been more than doubled, and those of the freight service have been quadrupled within the past 15 years.

If one compares the cost of railway-transportation in the United States with that in England and Europe, one is surprised at the smaller cost which obtains in the United States as a consequence of the heavier car-loads and heavier trains employed. This means, of course, more wear upon the rails, tires of driving-wheels and all wheels of the rolling-stock—a condition which is to be met by higher grades of material. Of the vast quantity of steel put into rails and other railway-material, little is used in its best condition. It can all be improved by suitable heat-treatment.

It is the low cost of railway-transportation which permits the carrying of our vast agricultural, mineral and manufactured products to the seaports, at a profit for the producer, as well as the carrier. In the last decade, the cost of railway-transportation on the heavier rails has formed but a small percentage of the cost of cereals at shipping-ports; and the producers have received large returns for their crops. And, in general, the rapid development of all resources and the great increase of wealth in the United States have been largely due to the low rates of railway transportation on all material.

The Proposed American Specifications.

With regard to the rails manufactured by steel companies under the proposed American specifications, railway companies will wish to know whether or not the rails are guaranteed for a period of five years against unusual wear or breakage. If the specifications carry a guaranty, then the manufacturers will be responsible for the quality of the product. If, on the other hand, the railway companies must assume all responsibility for the product, then the specifications seem vague as to the physical properties that will be obtained with the best standard current practice and the chemical composition proposed.

It is true that provision is made for a piece of a rail where certain physical properties must stand a specified drop-test. This would confine the manufacturer to the production of rails that would stand that test, to the exclusion of the consideration of other physical properties which are essential to good rails.

Chemical Composition.—Unless the current practice should be colder rolling than is now in general use, the proposed composition does not promise any higher physical properties than have been exhibited by rails manufactured of approximately similar composition,—though of course not exactly, for these specifications are new, and of necessity drawn broadly, to cover a diversity of practice. For instance, the silicon may range from 0 to 0.20.

Physical Properties.—The method provided for ascertaining the physical properties of the metal in the rail-section, in case one drop-test gives an unfavorable result for five "blows" of steel, is decidedly cumbersome, and not so readily carried out as where the test is made from each blow, to trace the uniformity of the product and guide the manufacture.

The heights prescribed for the tup of 2000 lbs. for the impact tests on sections of different weights are not as suitable for useful tests as those now in current use.

Test-Piece and Methods of Testing.—The provisions that the drop-testing machine shall have a tup of 2000 lbs. weight, and the striking-face a radius of not more than 5 in., corresponds to general practice. But placing the rail upon the supports head-upwards only tests it for one general property. More information can be obtained by adding to this some tests upon the rails head-down, and some upon the sides. In this way the physical properties of the metal are determined to a greater extent than when the test is made only with the head upwards. Placing the supports 3 ft. apart is what the writer considers the best practice. That the anvil-block shall weigh 20,000 lbs. is not the usual practice; but it is to be commended.

The provisions as to samples for chemical analysis follow the present general usage. It is now customary to make carbon- and manganese-determinations for each blow, and a complete analysis for each day- and night-turn, representing the average of the other elements contained in the steel, including copper.

Section.—"A variation in height of $\frac{1}{64}$ of an inch less and $\frac{1}{32}$

of an inch greater than the specified height will be permitted." This is in accordance with a very old custom, to allow for the variations in roll-turning. But the variation permitted is larger than should be allowed, because it is too great to produce rails which can be laid in the tracks so that the running surfaces shall be even. The height can be, and should be, practically constant.

Weight.—"A variation of one-half of one per cent. for an entire order will be allowed. Rails shall be accepted and paid for according to actual weights." This is not the custom in the United States. The custom is to confine the weight as closely as possible to that specified for the section; and the rails are accepted practically by length instead of weight, though all payments are made on a tonnage-basis.

Length.—"The standard lengths of rails shall be 30 ft." This is not the standard of length for rails at the present time. A number of railway companies buy their rails 33 ft. long, and some 60 ft. long. "A variation of $\frac{1}{4}$ of an inch in length from that specified will be allowed." This means, in practice, that one rail may be half an inch longer or shorter than the next rail from the same bar. In re-laying rails in the track this necessitates a great deal of adjustment. One-eighth of an inch is all that need be granted in good practice.

Conclusions.

It would seem quite easy to draw up standard specifications for rails where the conditions of traffic are uniform from year to year. But where the traffic conditions, owing to commercial requirements, are increasing in severity all the time, standards which were ample at one time become unsuitable for a traffic which has doubled or trebled in severity.

There is a strong probability that in the future we shall obtain a benefit from mechanical and heat-treatment of the metal during manufacture, like that which accrued to the early rails, or even greater. (The influence was not then noticed.) This will help the chemical composition so that higher physical properties will be obtained for a given composition.

Although the members of the Institute may differ widely in their views as to details, it is beyond question that our periodical discussions have contributed to a progress in railway-

transportation greater than that of any other country in the world. And this progress itself has laid úpon us the necessity of studying, reviewing, testing and experimenting more carefully and continually than ever, in order to meet the new conditions which it has created.

STEPHEN W. BALDWIN, N. Y. City (communication to the Secretary): The specifications proposed by the American Committee, and appended to Mr. Webster's paper, are intended to establish standards of quality and methods of ascertaining quality which, while fair to both parties, will secure in each case, under the present conditions of practice, satisfactory rails. Without discussing them in this aspect of immediate usefulness, I wish to offer some suggestions, looking rather to future improvement in the manufacture. In other words, it seems to me that specifications based upon the existing state of the art might well include, or be accompanied in application by, provisions for the collection of such information, beyond the immediate question commercially involved, as would promote further technical progress. The inspection of rails under such specifications furnishes all the means of collecting such information on a large scale, and with scientific accuracy. It would be a pity not to utilize it to its full capacity. We may safely assume that both the maker and the user of rails are desirous of improving the process and its product; and that they are willing to co-operate to this end, by recording all facts bearing upon it. Such a co-operation requires that each party shall furnish to the other the facts known to him, so that a complete and trustworthy history of a representative portion of each lot of rails shall be accessible to both.

As will be seen, the suggestion I here offer relates more particularly to the information which could be, ought to be, and generally is not, furnished to the maker by the user. When a lot of rails has once been inspected and accepted, the manufacturer hears nothing more of them, unless he has given a guaranty of a certain number of years' wear, in which case he may have to pay the penalty of failure, without being able to trace its causes.

To make up this deficiency, I would propose:

1. That the R.R. Co. require from its inspector of rails a

report as to the ore used, the chemical composition of the steel, the results of physical tests, the method of manufacture (including the use of the direct or the indirect process, upright or horizontal furnaces, direct rolling from the ingot or re-heated blooms, the size of ingots and blooms, number of passes, length cut from the top of the ingot, finishing-temperature, condition of the rails as to straightness on the hot-bed), and any other points that might affect their quality. I do not mean that all these particulars should be items in the specifications. Certain things are required; but other things, as to which the practice is not dictated, should be noted;—and the maker should furnish to the inspector the opportunity for noting them.

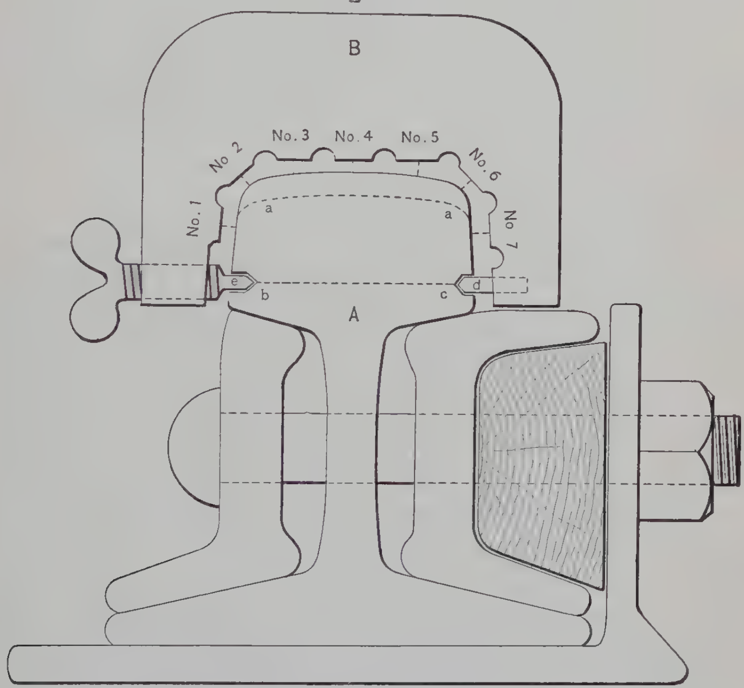
2. That the inspector select from each lot an agreed percentage (say 1 per cent.), to be known as "record-rails," painted and distinctly numbered, the heat-number and date of rolling being recorded. These rails should be placed in track at points designated by the R.R. engineer, and record should be kept of their location, at the time of which accurate measurement should be made and recorded of the working faces of the rail at each end and in the middle. This measurement and record should be repeated at the end of each year during the life of the rail. A comparison of these records will show the actual annual wear of the rail within 1–200th of an inch, and its total wear up to any given time. A suitable instrument for such measurement of wear will be described below.

3. That the R.R. Co. employ a competent examiner to make the tests and records of wear. His annual report should include the inspector's number; the heat-number; the date and place of location in track; the approximate number, character and speed of passing trains for the year; the weight of cars and locomotives; the conditions as to curve or tangent and grade; the amount of wear, in 200ths of an inch, on the face and interior side of the head; the kind of joints used; the general appearance of the rail; the local conditions of service, etc. Copies of these annual reports should be furnished to the rail-maker, who should be invited to send his own representative to make similar examination; and all possible facilities and information should be freely given to such representative.

4. That the results of all inspections and tests be at all times accessible to either party.

Figs. 1 and 2 illustrate the instrument for measuring wear. In Fig. 1, A shows the Pennsylvania Steel Co.'s Section No. 67, for 85-lb. rails. (The dotted line, *a*, *a*, represents the top of the American Society's 80-lb. section.) Two opposite $\frac{3}{16}$-in. holes are drilled into the head in the center of the rail, and at points 2 in. from the ends. The center-line, *b c*, between the holes of each pair, is the base-line for all measurements. It will be noted that this base-line is fixed, and will not be affected

Fig. 1



Instrument for Measuring the Wear of the Heads of Rails in Service.

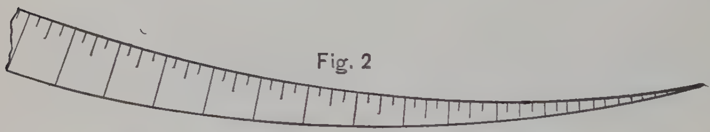
by wear or age; nor do the joints interfere with it. The hole on the inside (at *b*) is drilled deep enough to prevent its pointed end from being worn away by wheel-flanges. The drilling may be done at the mill or in the track.

B is a clamp, provided with points, as shown, to fit the two holes, so that, when adjusted, it will always occupy the same position, rendering the measurements taken in the space between the rail-head and the inner surface of the clamp (as shown by the dotted lines opposite No. 1, No. 2, etc.) perfectly

accurate for purposes of comparison. After the measurements have been taken, the holes *b* and *c* are filled with wax, to prevent oxidation.

As already pointed out, the base-line from which all measurements are taken is the line *b*, *c*, joining the *points* at the bottom of the two $\frac{3}{16}$-in. holes. These points are fixed and will not be disturbed by the wear of the rail. It is possible that the walls of these holes might be disturbed; in which case the holes would be reamed out at the time of taking the measurement. The stud *d* and the thumbscrew *e* come in contact with the rail only at the points, *b* and *c*.

The necessity of going below the surface to secure a fixed base-line arises from the fact that the surface is subject to



Tapering Scale, for Measuring the Wear of Rail-heads, in Connection with the Instrument Shown in Fig. 1.

change through wear and oxidation. Possibly better methods than those shown can be devised to secure accurate records of change due to wear. Any method by which this end is reached would accomplish the object in view, viz., a complete and reliable history of the rail from birth to death.

Fig. 2 represents a curved tapering scale with which the distance between the clamp and the rail-head at points No. 1 to No. 7, in Fig. 1, can be easily and closely measured. The taper here shown is 8 to 1; but it might easily be made 12, or even 20, to 1. The object of curving the scale is, that it may reach the bottom of pretty sharp depressions in the rail-face. If made straight, it would bridge them.

Types of Copper-Deposits in the Southern United States.

Discussion of the Paper of Mr. W. H. Weed, Presented at the Washington Meeting, February, 1900. (See *Trans.*, xxx., 449.)

PROF. J. H. KEMP, New York City (communication to the Secretary): Mr. Weed, quoting* my statement in *Ore-Deposits of the U. S. and Canada*, that solutions acid with sulphuric acid attack silicates such as feldspar and biotite, remove alumina or change it to kaolin, and cause the separation of free silica, questions the formation of kaolin. In this respect, my statement was incorrect. To the best of my belief, such a formation of kaolin would be chemically impossible. I have corrected the oversight for the next impression of my book.

SECRETARY'S NOTE.—The rest of this communication, as published in pamphlet form, was occupied with a reply to certain criticisms made in Mr. Weed's pamphlet. These having been withdrawn before the publication in this volume, the reply is also omitted here. Prof. Kemp's views on the matter are given in full in his paper on "The Deposits of Copper-Ores at Ducktown, Tennessee," p. 244 of this volume.—R. W. R.

The Constitution of Cast-Iron.

Discussion of Prof. Howe's Paper (see p. 318).

J. E. STEAD, Middlesborough, England (communication to the author): Prof. Howe's valuable paper on cast-iron brings forward most prominently the correct explanation of the part played by combined carbon in pearlite and cementite, in determining the strength and hardness of cast-iron. On a previous occasion I have shown that castings made by melting a white Cleveland iron and glazed iron, one containing 1.5 and the other from 4 to 5 per cent. of silicon, and each about 3 per cent. of carbon, were stronger than those made of ordinary foundry-iron; the difference in the final castings being a differ-

* *Trans.*, xxx., 491, 492.

ence in graphite, of which there was less in the mixture than in the ordinary foundry-iron.

Certainly I have had ample proof that, in Cleveland iron, provided the combined carbon does not exceed 0.8 per cent., the lower the graphite the better. I have long regarded this as an undoubted fact.

Prof. Howe's experience with charcoal- and coke-irons is rather different from mine. I have had nearly 30 years of practice in testing all kinds of English coke-irons and Swedish charcoal-irons; and, almost without exception, the charcoal-irons were found to contain more carbon than the irons made with coke. In coke-pigs, if the silicon be low, the carbon will be as high as in charcoal-pigs. The average carbon in hematite pig-iron, containing about 2.5 per cent. of silicon, is just below 4 per cent. Gray charcoal-irons, with between 0.8 and 1.25 per cent. of silicon, contain about 4.25 and often 4.4 per cent. of carbon.

I think the reason that iron can be melted in air-furnaces with so much better results than in cupolas is, that better control can be maintained in the former. The bath can be sampled, the samples tested, and the tapping delayed until the metal shows the desired qualities. In cupola-practice, strict attention must be given to the analysis of the material charged, since there is no means of making any modification in the metal after it has become fluid. I know, however, from 20 years of continuous experience, that, if the cupola be run scientifically, the ultimate mixture being calculated from the various pigs under command, results equal to those from any air-furnace can be obtained. The total carbon can be controlled to within 0.1 per cent. by mixing scrap-steel or iron with the pig-iron, and melting them together in a cupola. It is easy to mix pig with 4 per cent. carbon-steel and scrap, so as to obtain from the cupola castings with 3.25 per cent. carbon; but it is difficult to get less than that quantity. My experience is that steel-scrap, melted alone in a cupola with coke, yields a white iron with about 3 per cent. of carbon. More might be absorbed, but with a great expenditure of coke.

It is easy to lose carbon in a cupola in heating very gray iron. Snelus once found in a cupola a spongy mass of graphite of the shape of the original pig. The iron had combined

with just sufficient carbon to make it fluid, and this compound had liquated out, leaving the bulk of the graphite behind.

If cupola-furnaces are worked properly, with exact chemical control, castings of any desired properties can be obtained with a constancy equal to anything obtainable from an air-furnace. Take away the analytical guidance, and you have a most unscientific, unreliable and uncontrollable metallurgical implement. When there is no chemist, the air-furnace takes the first place. I certainly agree with Prof. Howe's general conclusion that it is advisable to keep the graphite as low as possible, and not to let the combined carbon be much above or below 0.7 per cent., the exact quantity depending greatly upon the amount of silicon, phosphorus and manganese which may be present. When these elements are at a minimum, the combined carbon may reach 0.9 per cent.; and as they are increased, it should be proportionally less.

Dr. R. Moldenke, New York City (communication to the Secretary): Prof. Howe's paper on the constitution of cast-iron is the clearest exposition of the subject, so far as the carbon effects are concerned, that has yet appeared. For one who has spent many years in the close study of cast-iron in its various forms, it is indeed a pleasure to follow the lines of argument as found in Sections I., II. and III. As far back as 1891 the writer had already based his work upon the assumption that cast-iron is really a steel of various carbon-content, with mechanically mixed graphite to weaken it. Once this idea becomes sufficiently impressed upon the mind of the careful observer he will be much interested to note the behavior of the various gray-iron castings in the machine-shop, and speculate upon the combined carbon-contents of the chips as they are gouged out of the work or are pared off like so much cheese.

What Prof. Howe writes of the effect of carbon on the physical properties of cast-iron will be endorsed by every foundry expert. A few remarks in connection with the allotropism of iron in the cast form, as met with in practice, may not be amiss. The "brake" action of carbon, which, Prof. Howe states, applies to a limited extent even in slow cooling, may be much more effective than is generally supposed; that

is, if the theory is at all correct. In castings up to 2 in. thick, when the silicon is below 0.30 per cent., the iron will be perfectly white and hard as glass, even though it be allowed to cool quite slowly in the sand. A tool will not touch this iron, and it takes at least twenty-four hours of annealing at a red heat before the lightest cuts can be taken off with the best of tool-steel. This behavior is even more marked in white-irons running over 3.50 per cent. in carbon, than in those containing less. The annealing referred to has the effect of turning the white fracture of the piece a shade darker, and if kept up at the proper temperature eventually results in the separation of Ledebur's "temper-carbon"—in fact, we have the "malleable casting." That carbon when alone would have some such braking effect is evident, as in one particular piece of the irons in question the sulphur was 0.02, manganese 0.12, silicon 0.21 and phosphorus 0.09 per cent., or practically a pure foundry-iron—the carbon being 4.12 per cent.

In discussing Section IV. of Prof. Howe's paper, one can heartily agree with his statement that "the lower the carbon, the stronger should the cast-iron 'of best proportion' be," provided everything else is equal. Now in this "everything else" should be included one item which is seldom thought of, strange to say, but which, it has appeared to the writer, offers the only natural explanation as to why charcoal-irons and coke-irons of identical composition, why even coke-irons of the same chemical composition, should differ so widely in their physical properties. This is in the degree of oxidation they have been subjected to in the making or re-melting. It may explain why Mr. Vannier finds the higher carbon-irons the stronger (the lower silicon-charcoal irons are always high in carbon and, being remarkably free from oxidation, are necessarily very strong) when everyone else finds the opposite to hold true as a general proposition.

The writer would refer to Prof. Ledebur's investigations on the oxidation taking place in a finished bath of steel, which explains why so many of our steels contain oxygen in combination, when in reality this should not be, if it were true that carbon takes all the oxygen as fast as it is presented. It has always seemed to the writer that the temperature of the bath has much to do with its chemical changes; for while manga-

nese added to a bath of steel removes practically all its oxygen for the time being, it does not show the same effect in a ladleful of dull foundry-iron. Aluminum, again, is better in this respect, but has the disadvantage of promoting the formation of graphite in the case of white-irons. To come now to the blast-furnace, is it not quite possible that the high temperature of the coke-furnace causes the melting of much of the oxide of iron before it is properly reduced and gives us pig-iron charged with more or less dissolved oxide? Charcoal-irons are purer not only because they are lower in sulphur, but because they are also freer from oxidation. The best coke-irons for physical strength in the "malleable" industry to-day are the so-called "Coke Malleables" and not the straight "Bessemers," which would do very well so far as their chemical composition is concerned. These coke malleables are blown specially, with plenty of coke and without forcing production. The finest foundry-iron we know of to-day is cold-blast charcoal-iron, the chemical composition of which is often not as good as much of our coke-product, but in the making of which there is the least chance for oxidation.

Perhaps this question of oxidation is dwelt upon too strongly, but the writer has long felt it to be the solution for the differences existing in the physical strength of the various kinds of iron of relatively the same composition. Several experiences are therefore given herewith which may furnish food for thought.

Some time ago the writer made a series of tests on burnt high-carbon steels. The various test-pieces were heated up in a reverberatory furnace (which itself was heated up gradually) and then plunged into cold water. The Le Chatelier pyrometer was used for determining the temperature up to which the pieces were heated. The range of the tests was from 1250° F. to 2300° F. At the last-named temperature the pieces were so badly burned that in the case of 1 per cent. carbon-steel they broke under the fingers, while with higher carbon, oxidation was complete before that point was reached. The subsequent chemical investigation revealed the presence of oxygen in increasing quantities as the burning was heavier, one piece showing over 1 per cent. in oxygen-content. The method of determining the oxygen, though crude, was effective. It consisted

in treating 10 grammes of the crushed material with the double chlorides of copper and potassium, burning off the carbon and dissolving out the silica. The remaining spangles of Fe_3O_4 contained the oxygen. The subsequent study in connection with physical tests was very interesting indeed, as it showed the weakening effect of the oxygen, which at first amounted to a film of oxide between the crystals of steel, and finally a solution resulting in distinct bright grains, as of crumbling adamant.

The above statements may explain the bad effects produced by the use of burnt scrap in cupola or furnace. As the first-named process rather aids the oxidation, if anything, is not the inferiority of the iron we get due to the dissolved oxide introduced with the overheated scrap? We all know that cast-iron accidentally introduced into an annealing pot for malleable castings comes out peculiarly rotten, with a blue and banded fracture. Material of this kind goes either into sash-weights or back to the blast-furnace.

It may be objected that what has been said so far applies only to overheated, and not to melted material. But the "malleable" industry furnishes an illustrative experience which is much dreaded and very expensive. When the same hearth is used for a number of heats, the furnace bottom becomes charged with pools of iron, which are burned up in the heating between charges and at night. Most of this material can be slagged off as a silicate, but enough remains to occasionally ruin a heat by "coming up" and dissolving in the bath. This usually happens when the iron is exceedingly hot and the bottom is carelessly prepared. Now, this iron is very fine to the eye, and when tapped runs out into the hand-ladles beautifully. This slight lowering of the temperature, however, is sufficient to immediately skull up the ladles, and two or three applications ends their usefulness for the time being. The molds will all be found short-poured, the castings full of blow-holes, and the iron, though apparently of proper chemical composition, will not anneal. Here is an occurrence which may well puzzle the inexperienced chemist; for he finds his silicon, sulphur, manganese, phosphorus and total carbon all right, yet his iron will not anneal and causes all kinds of trouble in the foundry. What is still worse, it will keep on doing so

until the scrap produced has gradually been mixed up with so much good iron that the oxidation grows less and finally disappears. One thing the chemist will notice, however. When he dissolves his shotted-iron sample in nitric acid, the clear yellow solution (the carbon being all combined) will contain a number of floating black specks, which on investigation will prove to be Fe_3O_4. Here there is a clear case of dissolved oxide. When we consider that all kinds of mill-cinder, annealing-pots, salamanders, etc., go into our blast-furnaces, much of which must be very difficult to reduce, is it not very probable that we encounter weak pig-iron as a consequence of oxidation apart from a possible poor chemical composition?

The writer trusts that these views may be worthy of thought in the study of cast-iron. We have no means as yet of correcting this evil in the cupola or open-hearth furnace for gray-iron work, as the temperature admissible in either is not high enough to remove the oxidation, once it has taken place. The addition of ferro-silicon, or, still better, ferro-manganese, does much to save the heat in the case above described, but it can only be run into pigs and used sparingly in subsequent charges; it will not do for castings, thus corrected.

The writer, further, fully agrees with Prof. Howe's exposition of the cupola- and furnace-process; is pleased to find that he also condemns the expression "semi-steel;" and can, finally, confirm the claim that ferro-silicon enables one to use more scrap in the cupola. The statements that burned-out silicon may be replaced by the addition of ferro-silicon, and that the carbon takes care of itself in the case of using scrap, are fully in accordance with the writer's experience. It may interest others to know that it is perfectly possible to run all-scrap heats when care is used to charge the cupola properly with the scrap and ferro-silicon well mixed and in light charges, and, where a large bull-ladle is used, to assist the mixing after the iron is tapped. The writer was once forced, in the absence of pig-iron from the metal-yard, to do this very thing long enough to prove the truth of the assertion with daily 50-ton heats. It is not a good plan to pursue, however, as the risk from bad mixing is great, and the principle of putting into your melting-apparatus as nearly the same iron as you wish to get out of it

holds good in the cupola as well as in the hearth-furnace. Only when pig-iron ranges too high in price should it become necessary to use an excess of scrap in the daily mixture.

In conclusion, the writer hopes that some one with more time at his disposal may look into the question of oxidation in foundry-irons, so that more light may be shed upon a question which seems to affect powerfully the unexpected variations in the physical strength of irons of identical chemical composition.

T. F. WITHERBEE, Durango, Mexico (communication to the Secretary): Prof. Howe seems to have given a very satisfactory hypothesis of the constitution of cast-iron, and its behavior, according to the proportion and kind of carbon contained in it, particularly from the standpoint of strength: but may not one point have been neglected, or, perhaps, not yet reached? Namely, granted that iron with lower total carbon, even with only 0.80 per cent. combined, could be made in the blast-furnace, how would that kind of iron stand the machine-shop test of turning, drilling, etc.

From my observations of the blast-furnace reactions, I cannot agree with Prof. Howe's theory that desulphurization takes place in the crucible, or by the action of carbon alone, except as the combustion of carbon furnishes heat for the reaction with lime. In the formula given in Mr. Howe's paper (page 337), the sulphur appears combined with calcium, as a result of a reaction upon lime. But under normal conditions lime does not exist in the crucible, except as a slag-constituent—*i.e.*, a silicate—as, indeed, this formula shows. A furnace may be said to have a grate, as a stove has; only, in the former, the grate is a layer of fuel, and during normal work nothing solid except fuel is seen at the tuyeres. Should this grate be destroyed in any way, then, and then only, solid lumps (usually black) are sometimes seen. These I have never known to be anything but lumps of lime, coated with iron-oxide or iron-slag.

In high-silicon pig, usually made with a more *acid* slag, the sulphur is sometimes quite high, as compared with ordinary foundry-iron. Perhaps this is an indication that carbon alone, as a simple heat-producer, is not sufficient to desulphurize.

Every furnaceman knows how fatal "slips" (even comparatively slight ones) are to the production of low-sulphur pig. Yet, if carbon desulphurizes in the blast-furnace, in which, as Prof. Howe says, the bath of molten iron "is penetrated by a solid column of incandescent coke," this action of carbon should not be disturbed by a slip above, which could not alter the previous condition thus existing.

Again, when charcoal, a fuel extremely low in sulphur, is used, there is no trouble in making high-sulphur pig, provided the furnace is working cold or short of lime; and yet the crucible is filled with incandescent fuel. May it not be equally plausible to suppose that, in other cases, the fuel in the crucible may be a *source* of sulphur in the iron, instead of a desulphurizer? In re-melting in the cupola, when particularly low sulphur is desired, extra care is taken that the fuel used be low in that element.

In ordinary foundry-work, it is not uncommon that a first-class pig is condemned by reason of the quality of the castings, which is really due to the sulphur taken up in the cupola from the fuel, and not contained in the original pig. Again, it is not uncommon that the sulphur in different parts of a single cast from the blast-furnace varies greatly, being below the limit of 0.05 per cent. in one part, and perhaps 0.2 per cent. or more in another.

As already observed, derangements of the furnace, such as slips, or water-leaks, which do not disturb the conditions in the crucible, are followed by higher sulphur in the pig. Whatever may be the cause of high-sulphur, the blast-furnace operator seems to have but one remedy, namely, a sufficiently high heat, together with the proper amount of lime.

As a *guess*, I would locate the zone of desulphurization in the blast-furnace above the zone of silicon-reduction. The train of experiments which led me to this tentative view may be of interest:

On a certain occasion, some four years ago, the furnace at Maysville, Wis., of which I had charge, worked hot, or "gray," and yielded the well-known smoky gas, which either refuses altogether to burn, or burns only fitfully; so that, through the lack of effective fuel-gas under the boilers, it was paralyzed for want of blast. After vainly trying for hours to

raise steam with wood (under boilers without grates), and having no supply of oil for fuel. I thought of using water-gas, produced by turning a 1-in. jet of steam into a tuyere. The effect was immediate. The characteristic hydrogen flame appeared; and in half an hour steam was blowing off. Afterwards, when making malleable Bessemer iron on a narrow silicon-limit, the silicon-percentages gave some trouble. If they showed a tendency to run too low, the old method of slowing down the engines usually sufficed: but over-blowing, to counteract the opposite tendency, was not so satisfactory.

Now, in the case of the smoky gas, caused by too hot a furnace, the effect of the steam was considered as in part due to the cooling which it caused. And, high silicon being likewise ascribed to excessive temperature, the same remedy, steam, was tried, and with good results. Hence, since high sulphur may come from a cold furnace, it was natural to suppose that, as the silicon was brought down, the sulphur would go up. But this was not the case, unless the steaming was largely overdone. These observations led to the theory that desulphurization takes place above the zone of silicon-reduction, by means of *heat*, aided by gases charged with lime-dust. This dust seems to be formed *near the tuyeres*, for, as is well known, when the cinder is allowed to get too high, all fumes from stove- and boiler-stacks are stopped. Perhaps the same *lime blast* (so to speak) attacks the free silica of the charge, a substance which, as we are taught, could not be melted alone in the blast-furnace.

It appears that the ability of ferro-silicon to "carry scrap" is questioned, or, as Prof. Howe puts it, "ridiculed." While Mexico is not very well posted in the use of pig-iron, there is not a foundryman in the Republic who cannot testify to the usefulness of ferro-silicon as a scrap-carrier. It is the practice here to buy car-wheels (because they are cheap), and mix them, regularly or occasionally, with high-silicon iron. Some eleven years ago I made, at Durango, a large number of light pulleys, 18 in. in diameter, with the rims cast only $\frac{3}{16}$ in. thick, from a mixture of the hardest kind of white charcoal-iron, containing 0.31 per cent. silicon, with 20 per cent. of iron carrying 13.21 per cent. of silicon. The result was excellent; the pulleys

turned soft and tough; the chips came off in curls, something like those of wrought-iron or steel, instead of semi-powdery chips, like those of ordinary cast-iron.

The white iron showed, on analysis, only a few floating specks of graphite; and the solution had a light lemon-color. The pulleys contained 2.52 per cent. of silicon, showing but a small loss in cupola-melting.

Neither the graphitic nor the combined carbon was determined in the pulleys, but their fracture was gray and finely crystalline.

Of course, the term "scrap," as used by foundrymen, really means nothing as to the nature or quality of the material thus designated. There is scrap, and scrap. One man may be melting fragments of old sewing-machines or stove-plates—a material which would, in the cupola, "carry" itself, and more too; while another might be working up a lot of old plow-points, which would need a good deal of help to make soft castings. In short, to many foundrymen "scrap" signifies any cast-iron which is not crude pig-iron.

Prof. Howe (communication to the Secretary): I quite agree with Mr. Witherbee that heat is an essential element in desulphurization; and, indeed, this follows from my words. I look upon carbon as essentially the desulphurizing agent, through its reducing the lime of the slag to the calcium which unites with the sulphur to form calcium sulphide. It is a fact too familiar to need special re-statement that the deoxidizing power of carbon increases with the temperature. Carbon, then, I take to be the active agent, and high temperature a permissive condition of desulphurization.

It is true that the fuel may be at the same time the source and the remover of sulphur. So far as it introduces sulphur into the furnace, it is a source thereof. So far as it deoxidizes lime, it is a remover of sulphur. There is nothing inconsistent in the two *rôles.* If the permissive conditions of high temperature and a highly basic slag (*i.e.*, a slag from which calcium can readily be deoxidized) are present, then the deoxidizing power of the carbon does, otherwise it does not, take effect.

The practice of "steaming" described by Mr. Witherbee is extremely interesting; but I do not think it conflicts with the

theories which I have put forward. We do not know enough of the facts to know how the steam acted.

Of course, my explanation may be wrong; but I see no other way of explaining the well-known fact that heat and lime do desulphurize, except that they do so by permitting the reduction of calcium through carbon.

As against Mr. Witherbee's idea that desulphurization habitually occurs above the zone of silicon-reduction, I have been informed that, in many cases in which a furnace was working normally and making a low-sulphur iron, the iron which has run into the tuyeres has been found to be white, and rich in sulphur.

I shall welcome any other explanation of the desulphurizing-action in the blast-furnace, because there are certain phenomena which my explanation does not fully cover. There is, for instance, the fact that, in the cupola, the amount of sulphur taken up by the iron is inversely as the temperature. Of course, this may be due to the reaction which I have described. At the same time, the explanation does not seem altogether satisfactory.

Mr. Witherbee is in error if he supposes that I regard the lime as present in a free state. My formula shows that I refer to the reduction of calcium, not from lime, but from slag.

The fact that a leak, or anything which cools the crucible, raises the sulphur, is wholly in accordance with my theory. Cooling the crucible simply removes one of the permissive conditions of the desulphurization by carbon.

I did not in my paper enunciate in full my idea of desulphurization in the blast-furnace, since that was somewhat foreign to my immediate subject. Let me say, here, that I look upon it as taking place by the reaction which I gave: that high temperature is a necessary condition, because it strengthens the reducing power of carbon; and that high lime is another permissive condition, because the more lime there is in the slag, the more readily can a part of that lime be reduced to calcium. Lime also favors high temperature indirectly, (1) on the general principle that the more infusible the slag, all other things equal, the higher will be the hearth-temperature; and (2) because a very limy, and hence pasty, slag gums over the interior of the crucible, thus in effect thickening the walls, and so lessen-

ing the transfer of heat outward through them. No doubt there are other conditions affecting desulphurization; but these appear to me to be the main ones.

It seems certain that sulphur is removed as sulphide of calcium; that this calcium enters the furnace as lime; and that it cannot remove the sulphur unless it is reduced from lime to calcium. If this be true, then it follows that the deoxidation of the lime to calcium is an essential step in desulphurizing, and that this deoxidation cannot take place except through some deoxidizing agent. That agent must be something in addition to heat; and what it can be, except carbon, I do not see.

Mr. Witherbee (communication to the Secretary): While it is a fact that sulphur appears in the slag as calcium sulphide, it is not the fact that all the sulphur in the charge always leaves the furnace as such. I have repeatedly seen a stream of burning sulphur run out with the slag, even when the pig-iron produced was very low in that element. Our late fellow-member, Dr. August Wendell, once called my attention to a yellow coating, an eighth of an inch, or even more, in thickness, on the cakes of slag from the Kloman cinder-cooler at Cedar Point furnace, Port Henry, N. Y., which proved to be sulphur. It appeared to have exuded out of the body of the cinder-cake. The cinder had been caught in cast-iron pots of sugar-loaf form, and 1.75 tons' capacity, submerged in water nearly to their tops.

Since, in the blast-furnace, iron oxide is known to be reduced to iron high above the tuyeres, and silica to silicon near, but not below, the tuyeres, what good reason is there to suppose that lime is not reduced to calcium before reaching the crucible, which surely is not the hottest, and therefore should not be the most active, zone of reduction? I have seen analyses of pig-iron showing calcium, but of course it could not be known where it had been reduced. The point that I sought to make against the idea that desulphurization occurred habitually and entirely in the hearth was, that "slips," which do not disturb the conditions in the crucible, generally raise the sulphur. Hence I reasoned that disturbed conditions *somewhere* above the tuyeres, above the zone of silica-reduction, and out of the reach of the cooling-effects of steaming, were responsible for the higher sulphur.

It is a common experience of furnacemen that, when a furnace is changing from hot to cold, or *vice versa*, there is a marked difference, even visible to the eye, in the sulphur in different beds, seeming to indicate that the molten iron in the crucible was in layers as regards sulphur-contents, just as would happen if different qualities of iron descended into it from the top, as a result of changed conditions above. As to the running of white, high-sulphur iron into the tuyeres of a *normally* working furnace, it would indicate to me that possibly it was the result of the melting-off of an accumulation from a former abnormal working, and that the iron was white by reason of the high sulphur, although its white grade *could* be the result of the bessemerizing by the blast of a pocket of iron. Indeed, its running into the tuyeres would indicate such a pocket—which I have known to occur, even to the extent of dephosphorizing from 0.4 down to 0.03 P in front of a tuyere.

Mr. Howe and myself differ, not as to *how* desulphurization takes place, but as to *where*; and we may both be right—or wrong.

The Effect of Heat-Treatment on Crucible Steel Containing One Per Cent. of Carbon.

Discussion of Mr. Sargent's paper (see p. 303).

Henry D. Hibbard, New York City (communication to the Secretary): The title of Mr. Sargent's paper is somewhat misleading, since the paper itself relates chiefly to various kinds of annealing and their effects, and in very small part only to heat-treatment proper. This term has a well-defined meaning in steel metallurgy, and always includes a rate of cooling faster than the material treated would have in the open air. In bringing about this accelerated rate of cooling, some medium other than air at rest is brought into contact with the heated steel. Usually a liquid (almost always either oil or water) is employed; but for certain steels a blast of air, and for others an easily fusible or soft metal, such as lead (either solid or melted), may be used. Heat-treatment usually includes also subsequent moderate heating, followed, it may be, with another accelerated cooling.

Several of the samples referred to by Mr. Sargent were heat-treated (quenched), it is true; but these constitute but a small fraction of the whole; and the reported physical tests include only one really "heat-treated" sample.

The "critical point" of a steel, when only one such point is referred to, is usually considered to be that at which the steel will harden when quenched—that is, W of Brinell or Ar_3 of Osmond. But in this paper the critical point for the steel examined is stated to be 680° C., and the physical test is given of a sample quenched at that temperature. Now, in a hardened piece of carbon-steel containing 1 per cent. of carbon, the elastic limit will be nearly or quite as great as the tensile strength. There will be practically no elongation. But this sample, quenched at 680° C., has an elastic limit of less than half the tensile strength and an elongation of 12 per cent. in 2 in. Therefore we must conclude that the steel was not hardened. This constitutes a discrepancy, indicating possibly that the critical point at 680° C. is one of the minor points which, in that case, should hardly be characterized as *the* critical point.

The Bryan Mill as a Crusher and Amalgamator.

Continued Discussion of the Paper of Mr. E. A. H. Tays (*Trans.*, xxix., 776 and 1054.)

Mr. Tays (communication to the Secretary): Mr. Wynne's criticism of my paper* brings forward a few points which are really important, and might properly have been considered in the original paper. By calling attention to them he has rendered me a service.

It is quite true, as Mr. Wynne says, that, in the tests reported by me, the Bryan mill was always working at a relative disadvantage, and my comparison of the work of this mill with that of the stamp-battery should be interpreted, therefore, so much the more favorably to the mill.

Of course, wire screens can be used to advantage on the Bryan mill, if they are not of smaller size than 30-mesh; but

* *Trans.*, xxix., 1054.

if of smaller size and, as is usual in that case, of finer wire, whether iron or brass, trouble will be experienced in keeping them whole. Screens of such sizes not only wear out rapidly, but are liable to have large holes punched through them at short intervals, especially when the dies are new, the inner basin of the mortar is consequently shallow, and the discharge is low. The use of tin screens on the Bryan mill is, for similar reasons, obviously out of the question.

I still believe that the improvements I have suggested would give a better mill for working free-gold ores than the present type. I cannot see that the hardness of the ore, however it may affect the crushing capacity, has anything to do with the amalgamating efficiency of the mill. Mr. Wynne says: "The inventor has given us a machine well adapted to the work for which it was designed, namely, *the crushing and amalgamation of soft ores.*" (The italics are mine.) I think the manufacturers might well take exception to this statement, as there is no reason why the Bryan mill, any more than the stamp-battery, should be designated specially for the crushing of *soft* ores. Of course, so far as crushing is concerned, it will do much better on that class of ore; but, for that matter, so will the stamp-battery. But in amalgamation after crushing, the degree of hardness of the ore can make no difference in the merits of the machine as an amalgamator, provided the ore be "free-milling." I would undertake to produce as much bullion from a hard, free-milling rock as from a very soft, free-milling rock of the same value, crushing and amalgamating both in the Bryan mill. With all due deference to Mr. Wynne's asserted larger experience with the Bryan mill, I must still differ with him with regard to the amount of amalgam that can be produced in the basin or mortar, and the reasons for this; and also with regard to the best manner of treating the ores.

I must also, in common justice, decidedly object to his statement that "the principal cause of failure to amalgamate satisfactorily in the Bryan mill" is "the want of experience and practical knowledge on the part of *most amalgamators.*" This statement seems to me both unjust and absurd. If "most" of the persons actually operating a given invention are without experience, pray who has the experience?

My experience goes to prove that Mr. Wynne's proposed

method of amalgamation in the Bryan mill is extremely faulty.

His first proposition is, that enough quicksilver should be used to keep the amalgam liquid. This, in my judgment, is just what should not be done. He advises the operator, secondly, "to replace the old dies, when a little more than half worn-out, with new ones." I fail to see how this would affect amalgamation or increase the amount of amalgam caught in the mortar; on the contrary, the deeper the basin, the more prone the amalgam, soft or hard, to remain inside it. And thirdly, he thinks it best "to clean up the mill at least every two weeks, or oftener, if rich ore is being treated." This recommendation is quite superfluous and inadequate. During the last year the Bryan mill was run here it was cleaned up every three days, even on low-grade ore; and this is especially necessary when the dies are new.

Mr. Wynne's inference, "it is evident that Mr. Tays endeavored to amalgamate quite 'hard,'" is incorrect. During the last two years our aim has been to keep at about the consistency of fresh butter the amalgam which gathered in the annular space between the dies and outer periphery. However, with a plate set as suggested by me,* the quicksilver should be fed so as to do just what Mr. Wynne condemned, namely, "to amalgamate quite 'hard,' as is done in the stamp-battery," and this could be done, in that event, without any fear that "the swash of the pulp would scour off portions of the hard amalgam, ... and dash it through the screens," as Mr. Wynne apprehends would be the case. At least there would be, in this respect, no more danger than exists in the stamp-battery—in other words, very little indeed.

To a certain extent, Mr. Wynne's statement that the apron-plates "are an addition to both the battery and the mill" is true; but they are an absolutely necessary addition, and a component part of each, if the securing of bullion is the end sought. Either apparatus would make but a sorry showing without the outside apron. Primarily, both the stamp-battery and the mill are crushers. In some plants, where batteries are used, no attempt is made to catch amalgam inside the battery-

* *Trans.*, xxix., 780.

mortar, but the outside plates are relied on entirely. "Much of the amalgam caught on the outside plates of the Bryan mill" may have been, as Mr. Wynne says, "unnecessarily dashed out," nevertheless, it was caught. Our experience with the Bryan mill was, that for two or three days the apron-plates would yield about the same amount of amalgam (usually a little more) as one of the battery-aprons; but on the third or fourth day, the amount caught on the aprons of the Bryan mill would be more than doubled—the greater part being obtained from the first two feet of the upper plate. For this reason the mill was cleaned up every third day during the last year of its run, as I have stated.

Mr. Wynne says: "The total yield would have been differently divided between inside and outside if the amalgamation had been properly conducted." Well-conducted practice with the mill, as now built, does not sustain this theory. I have no doubt, however, that the theory would be fully sustained with a mill constructed and run as suggested by me in my original article.

I have fully compared the two crushers, and will here repeat that, with the same ores, the 4-foot Bryan mill will crush more than a 5-stamp battery; and with the necessary adjunct, the apron, will produce as large a percentage of bullion as the battery with its necessary apron.

In treating hard ores the rock should be passed through the customary preliminary crusher and then to a fine crusher, say of the "Gates" or "Comet" type, feeding from $\frac{1}{4}$-in. to $\frac{1}{2}$-in. stuff to the mill. In this case the mill will crush much more than a battery fed with material of the same size, though perhaps not quite as much more as when softer ores are crushed.

The advantage of fine-crushing before feeding, even to a battery, is coming to be recognized. One of the San Francisco iron-works has already put on the market a stamp-mill so arranged.

There is no such "violent centrifugal motion of the pulp in the Bryan mill" as, in Mr. Wynne's opinion, "diminishes the clogging of screens by clay," or other matter. The pulp flows around, following the outer periphery, in a rising and falling wave; and my experience is that the screens require about as much care as those of the batteries, in order to keep them clean, so as to obtain a free discharge.

The danger to which the screens are exposed, and the greatest wear and tear which they receive, is due to pieces of rock (where $1\frac{1}{2}$- to 2-in. sizes are fed), caught by the sharp edge of the wheel or roller and snapped off on a tangent against the screen, either breaking it, or going completely through it. With ore broken to a size not exceeding $\frac{1}{2}$-in., a Russia-iron screen would last a long time in the Bryan mill. In one run with our mill on very hard rock, which we had to feed as it came from the coarse crusher, I used inside fend-screens of $\frac{1}{4}$-in. mesh. This effectively protected the outer screen; but in a short time the interstices between the screens became so far filled up with sand that even water would not pass through. I was forced to take out the fend-screens: but I have since thought that they would have worked fairly well had they been placed on the outside.

Regarding screens, I will add that I fully explained in my paper that the Bryan mill was run with a slot-punched Russia-iron screen, and the batteries with tin screens. The tin screens, whatever the size of hole, give a discharge-area of about four-ninths of the total surface. The Russia-iron slot-punched screen, on the other hand, gives a discharge-area of but about one-sixth of the total surface; so here again the advantage in the test was largely on the side of the batteries.

As to the class of screens used in the tests made with the batteries alone, I would say that Mr. Wynne's surmise that the wire screens may have been "of thick iron wire, and rusty," does not fit the facts. In the first case, as I have stated, screens between 10-mesh and 30-mesh were used; and I venture to say that I know of no screens of those sizes made with "thick" wire, nor have I ever seen screens made with such wire used on batteries. Wire screens, as far as I have observed, are usually made of fine soft wire, varying in size with the mesh, and woven so that the area of free discharge is about half the total surface. The larger the mesh, the larger the wire in proportion; and this is the case up to a $\frac{1}{8}$-inch mesh.

With the tin screens, the smaller the hole (or mesh) the thinner the sheet; but the discharge-surface is always about four-ninths of the total area. The advantage, then, would seem to be slightly in favor of the wire screens, so far as discharge is concerned.

In my practice, however, I have found, as already stated, that the output through a tin screen was somewhat greater than through a wire screen of the same relative size or mesh, this excess being as much as 14 per cent., according to tests made by runs of a month each, in 1895 and 1898. The wire screens used comprised sizes from 10- to 30-mesh, and were not made of ⅛-in. wire, but were of the "standard" make, in common use.

I have noticed that the tin screens do not clog up as badly or as rapidly as the wire screens, and that they are easier to keep clean. The reasons for this, to those who have used both, are obvious. The tin screens wear out more rapidly than the wire, but, on the other hand, they are much cheaper.

D. W. C. Nelson, Baker City, Oregon (communication to the Secretary): Having read with considerable interest the discussion going on in the *Transactions* of the Institute with regard to the Bryan mill as a crusher and amalgamator compared with the stamp-battery, and having had experience in the operation of both, I venture to think a few additional facts concerning the Bryan mill may be acceptable to our members.

The amalgamation in any mill cannot take place too early in the process. In the Bryan, I have saved as much as 75 per cent. inside the mortar, and without the use of inside plates—the principal part of the amalgam collecting, as fast as the gold is liberated from the matrix, in the eddy between the die and the central cone, where the pulp has least motion.

In the operation of the mill, the pulp runs around the mortar, next to the screens, in a rapid current; but towards the center, inside the rollers, the movement of the pulp is much slower; and as the gold is liberated it falls to the eddy-side of the current, and in practice is found amalgamated in mass around the cone in the center of the mortar. Here it is not subjected to the continuous grinding of the rollers in the pulp; and if the amalgam is kept at about the consistency of fresh-churned butter, or a trifle harder, it will be retained in the mortar.

The Bryan mill has this advantage over stamps, that it does not slime the ore, and the pulp is discharged in the best condition for subsequent concentration.

I have run two of these mills on pyritic ores in Baker county,

Oregon, for about 5 years, during the greater part of which time I had full charge of them. In crushing ore that contained from 10 to 15 per cent. of concentrates, I obtained the latter so clean that they carried only from 8 to 10 per cent. of silica, by running the pulp first over a row of Gilpin county "bumpers," and then over Johnston concentrators. This ore contained about $12 gold per ton, and some arsenic, zinc, lead, sulphur and iron. When I say that the tailings averaged only 90 cents per ton in gold, it will be evident that the quantity of slimes produced in the mill was very small.

A set of wearing-parts for this mill will crush from 5000 to 8000 tons of these pyritic ores before requiring to be replaced. I have run the Bryan mill on hard and soft ores, and have found it to do as good work on the one class as on the other, except as to the quantity crushed; but the 5-ft. Bryan mill will crush as much hard ore in 24 hours as any 850-lb. 10-stamp mill. I may add that, on the pyritic ores mentioned, I found the No. 8 slot Russia iron screen did the best work.

The "Hole-Contract" System in Mining.

Discussion of the Paper of Mr. Davis (see p. 628).

FRANK H. PROBERT, A.R.S.M., Morenci, Arizona (communication to the Secretary): The management of mines and the system of bookkeeping employed are subjects of great interest to mine-superintendents, and such papers as that of Mr. Davis cannot fail to attract attention. The Institution of Mining and Metallurgy, London, England, has done much within the last three years to promote discussion on the many systems adopted throughout the mining world; and any papers giving individual experience will benefit that class of men who are charged with the economical management of mining properties. It is often said that "a good mine shows a good manager," and more often that mismanagement is the chief cause of poor returns; or, as Mr. A. G. Charleton puts it, in his able paper on "Mining Accounts and Cost-Sheets,"* "accident may, and often

* *Trans. Inst. of Min. and Metallurgy*, vol. v., page 245.

does, electro-plate incompetency and gild 'brass,' a good man in charge of an unpayable property being seriously handicapped in competition with the inferior management of a richer 'bal.'" To a certain extent this is true; but, admitting that the most successful superintendent cannot make a mine in the absence of ore, there have been a great many mines closed down by reason of defective management. If there were more literature at the disposal of the inexperienced, more men willing to give their experience to the younger members of the profession, I think a great many mistakes of this kind could be avoided.

I have had considerable experience in setting contracts in all classes of rock, and have tried paying per ton of ore sent to the chutes, per ton of rock broken, per cubic yard stoped, and per linear foot of advance in headings; also, the "hole"-contract system. In every case I have found that contracts set on the amount of ground broken in stopes and the linear foot of advance in headings have been most satisfactory, both to the contractors and to the company.

In the mines of Meiseberg and Pfaffenberg, Neudorf, Germany, I gave the "hole"-system a thorough trial, but was obliged to return to the more common practice of measuring. In following lodes, or in stoping blocks of ore, the rock varies considerably within a short space, according to the quantity of mineral present and the character of the gangue. These things may be in favor of the contractor or against him, and differences between master and man are bound to occur. A rock very difficult to drill may break well when the hole is completed. By the "hole"-system this would go against the contractor; but if paid according to the amount of rock excavated, it might be to his advantage. If the rock is homogenous, the "hole"-contract system works well; but in any case it necessitates a great amount of work and most careful supervision on the part of the shift-bosses, who have to indicate the position, approximate depth and direction of the hole to be drilled, measure it, and keep a daily record of the work done. Moreover, where a foreman is responsible for the placing of all holes, the contractor becomes merely a tool in his hands, and his own powers of observation are discouraged. Men who are continually working in one place must become familiar with

the nature of the rock, and, in my opinion, are far better able to judge where a hole has to be drilled to bring down a certain piece of rock than a foreman who has so much other work to occupy his mind. Anything which encourages close observation and thought on the part of a miner makes him a better workman, by giving him confidence in himself and interest in his task.

Unless there are a number of shift-bosses, much time must be wasted by the contractors in waiting for their holes to be marked before commencing work, and to be measured afterwards. If the mines are extensive, it will take a man an hour or two to complete his round of inspection, which must necessitate not only a long wait for some of the miners, but hurried work on the part of the foreman; and then, if the holes are not well placed, or not bored to the proper depth, the contractor has to suffer. Mr. Davis says that if, in a heading, the round of holes is finished before the end of a shift, the difficulty is got over by having spare headings, in which the men can utilize their extra time. Surely, the time lost in taking down the machines, erecting others in the spare headings, transferring tools, etc., must go hard with the contractor. But if, on the other hand, the round of holes is not completed within the shift, that shift is lost to the company, as blasting is only done within certain hours; and it is of no use to fire holes which are not deep enough, or to fire some of the round and leave others standing.

Again, it is stated that in headings, after the contractors have become familiar with the ground, little direction on the part of the shift-boss is needed, the work being practically the same each day. In the event of the foreman discovering a hole which he considers misplaced, who is to blame?—the contractor, or the foreman who, according to the terms of the agreement, has to indicate the position, depth and direction of the holes? These difficulties must arise occasionally; and trouble may ensue.

The Coal-Fields of Northeastern China.

Discussion of the Paper of Prof. Drake (see p. 492).

F. Lynwood Garrison, Philadelphia, Pa. (communication to the Secretary): I have been specially interested in Mr. Drake's valuable contribution to our knowledge of the Chinese coal-areas, as I had occasion, about a year ago, to make a reconnoissance over some of the coal-fields in the Yangtse river valley. I noticed, as he appears to have done, certain peculiarities which may eventually prove to be characteristic of the Chinese coal-measures, at least in central and northern China.

The most striking feature, perhaps, is the invariable proximity of the great granite masses to those coal-deposits which have an anthracite character. In common with all other anthracite areas elsewhere, the Chinese show evidences of profound stratigraphical disturbances. The sedimentary rocks are folded, faulted and dislocated in a manner similar to those of the Pennsylvania anthracite-regions. It would seem that the intrusive granite had much to do with converting the original bituminous into present anthracite. The action of the granite was probably direct as a conveyor of heat, and indirect as dynamic force in dislocating, overturning, and compressing the coal-measures.

My stay in China was unfortunately cut short, so that I was unable to collect fossils, or to give this highly interesting and important subject more than passing attention.

Cholnoky* and Richthofen are practically agreed that these granite eruptions took place during the Tertiary period—probably the Eocene. This profound tectonic movement has had a most important effect upon the geological conditions in central and northern China, and will be, I am sure, a potent factor in the economic development. Evidences of disturbances and metamorphism are very abundant in the anthracite-areas of the Yangtse valley. I noticed the coal in them, as did Mr. Drake in northern China, to be often flaky and "slickensided."

* *Vorläufiger Berichte über meine Forschungsreise in China. Petermann's Mittl.*, xvl., 8–13 (1899).

*Composition of Chinese Coals.**

Anthracite.

Location.	Fixed Carbon.	Volatile Carbon.	Water.	Sulphur.	Ash.	Remarks.
1—Chaitang, west of Peking	89.81	3.08	2.67	....	4.44	Pumpelly—Researches, China, Mongolia and Japan, p. 123.
2—Munta-kau, west of Peking	80.75	5.43	2.42	....	11.40	" " p. 124.
3—Fangshau, southwest of Peking	86.62	4.64	2.64	....	6.10	" " "
4—Siangtung, Hunan Province	96.21	0.65	1.45	....	1.69	" " "
5—Lui-cha-ho, Southern Hunan	88.27	2.92	0.80	....	8.01	" " "
6—Kwei, Upper Yangtse in Hupeh	85.63	4.10	0.38	....	9.89	" " "
7—Tse-chau, Shansi Province	76.44	8.31	2.86	0.35	12.01	J. G. H. Glass, Rept. to Peking Syndicate, November, 1899, p. 109.
8—Siu-wu, Northern Honan	79.61	8.39	2.81	0.37	8.52	" " "
9—Ping-ting-chau, Northern Honan	75.51	9.50	2.80	0.58	11.61	" " "
10—Ching-wa, Northern Honan	78.61	6.06	2.72	0.41	12.20	" " p. 110.
11—Huai-king-fu, Northern Honan	81.63	7.51	2.74	0.44	7.68	" " "
12—Ta-yang, Shansi	72.83	16.41	3.54	0.31	6.91	" " "
13—Huai-king-fu, Northern Honan	79.13	10.63	2.00	0.34	7.90	" " p. 113.
14—Tse-chau, Shansi	80.03	4.54	2.24	0.37	12.70	" " "
15— " "	85.99	3.84	3.54	0.32	6.61	N. F. Drake, Trans. Am. Inst. Min. Eng., vol. xxx. (1900), p. 273.
16—Ta-yang, Southeast Shansi	82.74	5.55	1.55	0.25	10.15	" "
17—Ta-chi " "	86.09	2.61	2.75	0.31	8.53	" "
18—An-hui Province	88.00	8.30	1.10	....	2.60	Analysis of F. L. Garrison.
19— " "	87.76	7.80	2.00	....	2.44	"
20— " "	81.40	6.90	0.40	....	11.30	"
21—Hankow, Yangtse Valley	90.02	4.20	2.70	....	3.08	"
22—Hongay, Tong-king	85.04	5.86	2.20	....	6.90	"

Bituminous.

Location.	Fixed Carbon.	Volatile Carbon.	Water.	Sulphur.	Ash.	Remarks.
23—Heng-chau, Southern Hunan	71.80	15.89	0.65	....	11.66	Pumpelly—Researches, China, Mongolia and Japan, p. 125.
24—Tatung, Northern Shansi	65.30	28.69	1.47	....	4.54	" " "
25—Kaiping, Chili Province	62.85	29.53	0.47	0.98	7.15	Trans. Am. Inst. Mining Engineers, vol. xvi. (1887), p. 98.
26— " "	64.62	25.16	0.40	1.86	10.43	" "
27—Nanking, Yangtse Valley	59 00	25.48	3.52	....	12.00	Analysis of F. L. Garrison.
28—Kiang-si Province	71.40	23.20	2.20	....	3.20	" Makes hard, silvery coke.
29—Che-kiang Province	71.60	19.10	2.80	....	6.50	" Does not coke.
30—An-hui Province	70.76	21.40	3.40	....	4.44	" Cokes slightly.
31—Kaiping, Chili Province	60 10	26.10	1.60	....	12.20	" Makes fair coke.
32—Jehol, Mongolia	70.09	13.47	1.85	0.77	13.82	Percy's Metallurgy, Fuel, p. 347. Makes good coke.

* This table was originally published in *Mining and Metallurgy*, Jan. 15, 1901.

Cherts are also characteristic of the Yangtse valley beds. They are frequently black; I have one in my possession part black and part grayish-white, the line of demarcation being very sharp, the absorption of bituminous matter having apparently been stopped suddenly. Whether or not these black cherts are interbedded in the limestone, I am not certain, but incline to think they are.

Much of the coal that finds its way into the local markets in China is unusually high in ash; but I do not think it is fair to infer this to be characteristic. With one exception, all coal now produced in China is derived from native operations, and the Chinaman is not discriminating. Anything that will burn is coal, according to his notion. In the table on page 1009, carefully compiled from a number of sources, the Chinese coals, on the whole, make a fair showing as to composition.

The most important point brought up in Mr. Drake's paper is the question as to the age of the Chinese coal-measures. While it is true that the coal-fossils collected by Pumpelly were identified by Newberry as Mesozoic, later investigations by Richthofen, Loczy, Schenk, and others have thrown more light on this vexed subject; and I believe we are now safe in assuming the beds to be really Carboniferous. Schenk, of Leipzig, examined many specimens from the productive coal-measures and discovered a large number of characteristic species of Carboniferous plants. Of 41 of these species described by him, 25 are either themselves found, or have near analogues, in the coal-beds of other parts of the world; a few have sub-Carboniferous affinities; and a considerable number range upward to the Permian.*

At the time of my visit to the Yangtse valley fields, I was not aware that there had been any doubts as to the age of the Chinese coal; consequently I neglected to secure a collection of fossils. My subsequent work in China took me away altogether from the coal-areas, so that I never had another opportunity of collecting. The few fossils I noticed I took for granted to be Carboniferous. Some *Lepidodendra* I certainly identified, and I think a few *Sigillaria*, though I am not sure about the latter.

---

* *Die während der Reise des Grafen Bela Szechenyi in China gesammelten fossilen Pflanzen, von A. Schenk: Palaeontographica*, vol. xxxi., Cassel, 1885, pp. 163–182; also Richthofen's *China*, vol. iv., 1885, pp. 211–269.

The Richmond Coal-Basin.

Discussion of the Paper of Mr. Woodworth (see p. 477).

WARE B. GAY, Richmond, Va.: Having followed the remarks of Prof. Woodworth with great interest, especially his suggestions for drilling in the part of the coal-field on the south side of the James river, I would like to inquire of him if he reached his conclusions after fully considering the situation as existing upon the north side of the James?

My reason for this inquiry is, that upon the north side the eastern and western outcrops are much nearer each other than appears to me to be the case upon the south side, and also that the western outcrop on the north side is much more clearly defined than upon the south side.

It is now about twelve years since I first became interested in the Richmond coal-field—and until about six years ago I passed much time in investigation and spent thousands of dollars in developments.

About six years ago the properties in which I was more especially interested were leased to other parties, and since that time I have had little or nothing to do with the mining operations. I regret to say the price of coals has ruled so low during most of the time since the lease was made that the developments have not been as extensive as the lessees had originally intended.

The result of my investigations after considering all the theories, expert reports, legends and other information I could obtain bearing upon the subject, was the opinion, which I still hold, that the most practicable and most economical way for proving the extent and value of the field is by sinking slopes from the eastern outcrop, and by prosecuting such slopes in the vein and following the coal to the western outcrop, thus obtaining an actual cross-section in fact and not in theory.

Proceeding upon this hypothesis, I sought for the positions where this could probably be accomplished most quickly and develop a marketable coal-area as the work thus progressed. The outcrops on the north side being nearer each other, and

both eastern and western having been proved and worked for many years, I concluded that side the river to afford the best point for beginning operations, especially as a slope 1656 feet long then existed at the old Trent mine at Gayton. The unwatering of that old slope was proceeded with, and while this was being done a slope was also projected at the Dover mines upon the western outcrop, and driven far enough to determine the character and continuity of the vein and its pitch eastward, which is at about 40°, the pitch on the eastern outcrop being much less, or about 20°. The bottom of this 1656-foot slope is in good coal, and continues upon about the same pitch, and the promise of continuance of the vein is as good at the face as at any intermediate point. Overlying the vein in which this slope has been driven are two more veins of bituminous coal and one vein of the natural coke of semi-anthracite. This latter vein affords an excellent fuel for domestic use, and the three bituminous veins make good coke and are good steam-producers.

Upon the south side of the James, similar opportunities exist for the extension of slopes; and I firmly believe it to be the best way to open the Richmond coal-field, and less expensive in time and money than by deep and expensive drilling. The cost of the drilling alone will be more than that of the slopes, and in one case a means of continual output would be afforded, while in the other case, after the drilling had been completed, either slopes or shafts would be necessary for working the field.

Mr. Woodworth: I have given some consideration to the conditions on the north side of the James. The basin is narrower in that part of the field, and apparently less deep than on the south side of the river. The chief need of borings on the south side is to establish beyond doubt the existence of workable beds of coal in the great southern central tract, and to determine the depth at which such beds must be worked, if they can be worked at all.

The Missouri and Arkansas Zinc-Region.

Discussion of the Paper of Mr. Hedburg (see p. 379).

PROF. J. C. BRANNER, Stanford University, Cal. (communication to the Secretary): On p. 398, Mr. Hedburg mentions Marionite and Brannerite as ores of zinc. Neither of these has been authoritatively recognized as a distinct mineral species. Marionite, originally described by Elderhorst, was subsequently determined to be nothing else than hydrozincite. Analyses of the so-called Brannerite were sent by me to Prof. Penfield, who says it is a mixture of Smithsonite with some other mineral.

On p. 398, Mr. Hedburg says the zinc-bearing formation of North Arkansas "is recognized as the Upper Silurian." So far as my observation goes, the ores occur both in Lower Carboniferous and in Ordovician or Lower Silurian rocks, but nowhere in rocks known to be of Upper Silurian age. If Mr. Hedburg has any paleontological evidence of the Upper Silurian age of these rocks, or of any of them, he will confer a favor upon geologists by making it known.

On the same page is another statement in which I cannot concur. He says that in this region, "it can easily be seen that the largest fissure-deposits have been eroded and washed away, leaving here and there a few patches adhering to the hillsides." I am compelled to say that in many years' study of the geology of the region in question, I have never been able to recognize such a state of affairs as Mr. Hedburg here describes. The patches which he regards as remnants of fissure-veins, "adhering to the hillsides," I have found to be either the edges of bedded deposits, or portions of the zinc-bearing breccias, formed along old drainage-lines, and laid bare by the ordinary processes of erosion. That fissure-deposits have been partly removed by the same agency, goes without saying; but it is, in my judgment, no more true of North Arkansas than of any other mining-region that erosion has selected and washed away "the largest" deposits.

My own views of the region in question are given in detail

in my paper on "The Zinc- and Lead-Deposits of North Arkansas," presented to the Institute after the announcement, but before the publication, of Mr. Hedburg's paper.

F. Lynwood Garrison, Philadelphia, Pa. (communication to the Secretary): From a personal experience of three or more years in the Joplin region, I think Mr. Hedburg's figures for the cost of mining in what he calls "hard ground" are about correct, though by no means conservative. He has omitted, however, several items of expense, such as timbering, pumping, dead-work, repairs, interest and superintendence. The average yield in the Joplin district is about 4 to 5 per cent. of concentrates; that is, for every 100 tons of rough ore hoisted to the surface and passed through the mill there is a yield of from 4 to 5 tons of concentrates, worth, at present prices, about $25 per ton. According to Mr. Hedburg's figures, the mining of 100 tons of raw ore at 51 cents per ton would cost $51, or, on a 5 per cent. ore, about $10 per ton of concentrates. Adding from $4 to $5 (say $4) per ton for the items of expense above enumerated, we have $14. The cost of mechanical concentration of the ore is say 23.5 cents per ton, or $23.50 for the day's output of 100 tons of raw ore, representing $4.70 cost per ton of concentrates, which, added to $14, makes $18.70.

The royalties, as a rule, range from 10 to 20 per cent. Of late years, the higher figure has obtained; so we will take it at 20 per cent., which is calculated on the market-value of the concentrates. If that value be $25, the royalty is then $5 on each ton, which, added to the $18.70, makes $23.70, leaving a net profit to the miner of $1.30. It is plain from this calculation that very few of the smaller operators in the region can make money while paying a 20 per cent. royalty. Six to eight dollars per day net profit is not a suitable return on a mining investment of from $10,000 to $15,000. Of the 300 working-days in the year, it is unlikely that over two-thirds would be days in which ore was produced. A considerable allowance for dead-work, or days in which no ore is produced, must be made; and 200 working-days, yielding a net profit of say $7 per day, would give only $1400, which is by no means a sufficient return when all the risks are considered.

One great difficulty in the Joplin region is to obtain honest and efficient superintendence. From $75 to $100 per month is usually paid for this service; but it is seldom possible to get good men at these rates. Small mines, such as are above indicated, producing say 100 tons of crude ore per day, cannot stand a greater expense for superintendence, consequently many such enterprises have now been consolidated under one effective management.

I doubt if there has ever been a mining camp in this country in which people have been more humbugged and swindled than in Joplin. "Wild-cat promotion" was the order of the day during the boom of 1899. The would-be zinc-miners flocked there from all over the country; and not a few of those that made the worst mistakes were experienced mining men from other mineral districts. The history of this "boom" is yet to be written. Its victims number hundreds, and comprise widows and orphans, as well as millionaires.

Henry W. Nichols, Field Columbian Museum, Chicago, Ill. (communication to the Secretary): Two years ago, while collecting zinc-ores for the Paris Exposition, I visited the Rush Creek district of the Arkansas zinc-fields described by Mr. Hedburg. Although development had not proceeded far enough to exhibit much of the lay and nature of the deposits, yet I was able to make some observations, my interpretation of which leads to views regarding the mode of deposition, and the form of the lower portions of the deposit, somewhat different from those advanced by Mr. Hedburg. The additional notes here given may therefore prove interesting and pertinent, though they cover only a limited region around the mouth of the Buffalo Fork, and as far up-stream towards Yellville as Rush and Maryhattiana.

In strong contrast to the Joplin field, the region has a decidedly mountainous structure. The streams flow swiftly in deep narrow valleys, with only a strip of bottom- and terrace-land. They are flanked by limestone hills, rising precipitously from 400 to 1000 ft. above the valleys, to a maximum of 2000 ft. above sea-level.

The principal stream is the White river, quarter of a mile wide at low water, and fordable in a number of places, but

rising in times of extreme high water over 60 ft. It is bordered by a narrow strip of bottom-land, with terraces in places, behind which the hills rise very precipitously.

At Winnerva, three miles S. of Buffalo City, the Buffalo fork enters the White river from the S. and W. The Buffalo is the White river repeated upon a smaller scale. Into these main streams empty a multitude of creeks, each having its own deeply cut and narrow valley. The deep trenching and consequent exposure of bare rock make travel difficult, but prospecting easy. Most of the present mining consists in following the outcrops of ore which appear on the hill-sides.

The limestones lie in regular folds, which are well exposed along the transverse valleys, as are also numerous faults, some of great length and displacement. Although the uplift is generally thought to be of Paleozoic origin, there has been a continuation of the movement which is comparatively recent and rapid. The deep and narrow valleys with torrential streams which Mr. Hedburg interprets as due to cutting by former floods are more in accordance with the usual explanation, to the effect that the streams are rapidly cutting to base-level after an uplift of the region. That the folding has been rapid, is indicated not only by the narrow valleys and tumultuous streams, but more significantly by the extremely large amount of faulting in proportion to the strength of the folding, which, while very marked, includes nowhere sharp flexures.

As to the age of the ore-bearing rocks (in this instance, as I believe, an unimportant point for the miner), it is the consensus of present geological opinion that the Upper Silurian, mentioned by Mr. Hedburg, is not represented among these beds in which the mines are operated, and is confined to a comparatively thin bed of the Niagara period. The stratigraphy has been worked out by T. C. Hopkins, in his work upon the marbles of Arkansas, as well as by Branner and others. The paleontological evidence has since been discussed by H. S. Williams, Van Ingen and Stuart Weller; so that this question is now pretty well settled, except as to minor details. The rocks of the district belong to the Lower Carboniferous, Devonian and Lower Silurian (Ordovician) series, with one limestone (St. Clair) of Niagara age. They consist of limestones, with a few beds of shale, and one important sandstone. The limestones are metamorphic

and include several beds of marble. Most of them are more or less magnesian and siliceous. Often they are so impregnated with bitumen as to yield a strong odor when struck. Several beds of chert (the "flint" of the Joplin district) are included, but lie far above the ore-bearing rocks. By one who has gained some acquaintance with the region, the different strata may be readily recognized in the frequent outcrops along the hill-sides.

They lie in the following order, from the tops of the hills to the bottoms of the valleys of the district:*

Sub-Carboniferous, . . .	Boone cherts and limestones. Eureka shales (in part).
Devonian, ...	Sylamore sandstone (in places). Eureka shales (in part).
Upper Silurian (Niagara), .	St. Clair limestone.
Lower Silurian (Ordovician),	Polk Bayou limestone. Izard Blue limestone. Saccharoidal sandstone. Magnesian limestone.

The magnesian limestone of the epoch of the Calciferous sand-rock of New York is the principal ore-bearing horizon. Its upper limit is recognized on the hill-sides at a glance by the very strongly marked outcrop of the overlying saccharoidal sandstone.

South of the zinc-district, near Batesville, caves in the limestone are numerous. There is one not far from Buffalo City. Throughout the district, areas of brecciated limestone are common, showing former open ground, favorable to the deposition of ores. It is not uncommon to find the fragments re-cemented with the characteristic pink dolomite, well known in the Joplin fields, which, once seen, is readily recognized. In all the mines and prospects seen, this breccia of limestone cemented with dolomite was found. The folding and faulting, which tend to form open ground favorable to the deposition of ores, appear to be stronger along the Buffalo river than elsewhere in this section of the State.

Hopkins† noted eight faults along the immediate bluffs of the Buffalo river, and many others more or less remote from the stream. The ore-deposits follow and are controlled by the

* The names and the correlation are nearly those of H. S. Williams, *Ark. Geol. Survey*, vol. v., 1892. † *Ark. Geol. Survey*, vol. iv., 411-413 (1890). "Marbles."

faults. This is well exemplified in the string of openings along the Buffalo fork, near its mouth, which follow the great fault of the Buffalo valley: and it may be observed elsewhere as well. The deposits now under exploitation do not lie in the fault-fissures themselves: nor is it yet known whether any important deposits actually occur within the walls of any of the important faults.

The impression given by such brief examination as I was enabled to make was, that these great fissures have had a directing effect upon the ore-bearing solutions by acting either as conduits bringing in the waters from below, or as drains causing currents to flow towards them, and thus collecting the metals from wide areas.

The deposits themselves, where opened, assume a variety of forms. Those high up on the hill-sides generally differ somewhat from those in and below the floors of the valleys, although in many instances the deposits are continuous from the lower to the higher level. Most of them appear as vertical crevices with distinct walls, filled with a breccia of dolomitic limestone, cemented with pink or white dolomite and blende. From these fissures, offshoots have insinuated themselves into the bedding-planes of the country-rock, forming bedded-veins. Frequently these have been opened by mining high up on the hill-sides; and, in general, they are the characteristic forms of the upper deposits. Irregular branching forms, which appear occasionally, seem to be cavern-deposits. The ore from these is accompanied with chert in considerable quantity. Yet, although the limestones are in places very siliceous, and chert-beds occur on the hill-tops, the great majority of the mines visited by me were completely devoid of chert. Specimens of ore from many mines inspected at Buffalo City likewise were free from chert. On the other hand, chert is frequently mentioned in the report of the State Geological Survey as accompanying the ores; and the specimens from the collection of Richard D'Ailly, of Harrison, Ark., now in the Field Columbian Museum, show the proportion of chert usual in the better-known Missouri deposits. Giving due weight to these conflicting observations, it may be concluded that, while the Missouri deposits are essentially in chert, the Arkansas ores are essentially in limestone.

In many places the ore-bearing limestone is markedly fetid,

forming a "swine-stone." In none of the openings examined was any pyrite or marcasite found. Chalcopyrite, which is not unusual in many Missouri mines, could not be found here, although there are copper-prospects not far away. In the mines visited there was absolutely no lead. The lead-bearing deposits in other parts of the district appear in the Boone cherts, and hence belong to the horizon of the Joplin lead-zinc ores. In the upper mines, there is little crystallized calcite.

Although the deposits are often continuous from the highest to the lowest, there is a gradual change in character, according to the horizon of the ore. This change has not been traced, so far as I am aware, for any one spot, nor does it possess the hard and fast character of a mathematical proposition; yet it is one of the most noticeable results of a generalization of the characters displayed by the different mines of the district. The most striking change, and one that is often commented upon, is in the color of the ore. The ores from the topmost portions of the workable deposits are in general very light-colored, in some specimens almost white. The lower the specimens occur, the darker they appear, until in the White Eagle and the Creek Dig of the Maryhattiana they are decidedly dark. This dark color is due, not to an increase in iron-contents, but almost wholly to inclusions of bituminous matter, similar to that of the Wisconsin ores and of the fetid variety of the local magnesian limestone. It is probable that increased cadmium-contents of the ore in depth account for a part of this darkening of color, since the "turkey-fat" ore (calamine, colored with greenockite) is not an unusual accessory mineral. It is to be noted, also, that at the Morning Star, where the blende is darker than the position of the mine would warrant, accessory cadmium-minerals are especially abundant.

The ore becomes coarser in depth. At the upper limits, and for a very considerable distance below, it is all "crush-ore." Even where rich, it consists for the most part of films or thin veinlets, associated with dolomite cementing angular fragments of limestone breccia. In depth, the average thickness of the veinlets increases until, in the mines below water-level, it frequently happens that entire fragments have been replaced, and that much of the ore may be profitably separated by hand-sorting. Coincident with this increase of size occurs, as might

be expected, an average increase of richness. The amount of open ground also increases downward. The upper portions of the deposits were evidently formed in a brecciated open ground, which has since been cemented, so that actual openings are not very numerous. Going down, however, more open ground is encountered, as is testified by the increasing amounts of crystallized dolomite and calcite shown on the dumps. Moreover, the drill-men working in the valleys report a degree of trouble from open or loose ground altogether inconsistent with such conditions as are visible upon the hill-sides in the higher portions. For this tighter condition of the ground on the upper levels I can see no reason unless, indeed, it may be more apparent than real. It may be that the streams have excavated their valleys along the more open ground. As they have widened most in the upper portions, this has caused the edges of the valleys, with their mines, to lie against a barrier more resistant than the average rock of that horizon. If this is the case, the ground will grow more open as the mines penetrate the hill-side. Mr. Hedburg's hypothesis that the best of the ore-deposits have been eroded away by the streams is probably based upon similar reasoning. It would be very extraordinary, indeed, if the streams traversing any ore-bearing strata whatever should not remove more or less ore, and often valuable deposits. This has undoubtedly occurred in Arkansas, as elsewhere. Fragmentary deposits now lying upon the hill-sides abundantly testify to this. There is, however, no evidence to support Mr. Hedburg's assertion that the richest deposits have been eroded and washed away. These fragments do not represent the important deposits of the region, although, being the most visible, they were naturally among the first worked. The majority of the deposits which I visited were not of the character of "washes" upon the hill-side, but were deposits which had been developed by following stringers into the hill-side by means of an open cut, and then "facing up" the sheet of ore when it was reached. Many of these ore-bodies lie at all angles with the direction of the valleys. The miners believe that the faces of ore thus obtained run directly into and through the hill, in the form of beds conformable with the stratification, whereas, in most cases (perhaps in all), they are horizontal sheets, filling joints or fissures. The bedded deposits reported by Dr. Branner were not recognized

by me. At the time of my visit there was current in the district a theory that the deposits were bedded, and that there were three ore-bearing horizons, to which all deposits could be referred. A very slight examination suffices to show that the outcrops in the magnesian limestone of the hill-sides have no visible regularity whatever. This would, however, have no bearing upon Dr. Branner's hypothesis of the existence of both bedded and other deposits.

The deposits in this portion of the district are controlled in position by a system of faults, one of which appears to have directed the course of the Buffalo river as well. The deposits take the form of irregular areas of replacement of a brecciated magnesian limestone, and of fillings of pre-existent openings at and below the present water-level. From these areas ramify branches, filling joints, bedding-planes, shear-zones and sometimes former caverns, reaching upward as far as the saccharoidal sandstone, and occasionally beyond. As they extend upward they grow poorer, and the blende becomes less of a replacing, and more of a cementing, substance. The fractures might serve as a directing force upon the ore-deposits, either by acting as conduits bringing in the zinciferous solutions or as drains collecting them from a large area. In spite of the trend of present opinion, I believe that the former alternative is the more rational in this case. It appears much as if students of these deposits have been content to take a theory applicable to the deposits of Wisconsin and apply it to the ores of the Ozark uplift, without giving sufficient weight to differences in the conditions.

The ores appear in the limited district under consideration to be practically confined to the magnesian limestone, and to increase in quantity downward, either because the limestone is more bituminous or more open in the lower portions, or, more probably, as the result of a secondary downward concentration.

W. A. Fleming Jones, Mansfield, Mo. (communication to the Secretary): I take the liberty of correcting in Mr. Hedburg's valuable paper one or two inaccuracies relating to the outlying portions of the district, with which, possibly, he is less familiar than I.

In speaking of the Ozark region, from the Missouri river to the Arkansas line, Mr. Hedburg says the highest point is at

Cedar Gap, in Wright county. This is, indeed, the highest point on any line of railroad; but the summit of the Missouri Ozarks is Lead Hill, about 3 m. E. of Cedar Gap, and the same distance west of Mansfield. The altitude at Cedar Gap is about 1700 ft., while at Lead Hill it is 1797 ft.

Mr. Hedburg describes the "lead- and zinc-zone" as extending 75 m. E. and W. of Joplin. This is an inadequate statement. The producing field extends some 100 m. E. of Joplin, into Wright county, where lead- and zinc-ores have been mined in a desultory way for more than 30 years. Modern methods are now rapidly gaining ground; several complete concentration-plants have been erected during the past few years; and others are now (January, 1902) under construction.

Mr. Hedburg (communication to the Secretary): Prof. Branner is correct in saying that neither Marionite nor Brannerite has been authoritatively recognized as a distinct mineral species. My mention of them should therefore be construed only as indicating varieties of zinc-ore found in this region.

As to the age of the formation which is 500 ft. below the surface at Joplin, and appears on the tops of the hills in Arkansas, I have no paleontological evidence to offer; and I may have been mistaken in supposing it to have been recognized as the Upper Silurian. Yet, if the zinc-bearing formation on the surface at Joplin is Lower Carboniferous, the formation 500 ft. below would seem to be Upper rather than Lower Silurian. The Lower Carboniferous is found in northern Arkansas at a very few places only, on the tops of the highest hills. In my opinion, it was, in Arkansas as in Missouri, the original source of the zinc-ores; and I believe that their occurrence in lower strata is due to the fissures described in my paper, which extend down to the Lower Silurian, and were filled with ore-bearing solutions from the higher levels. Evidence of such fissures can be seen in the New York and White Eagle mines. As a consequence of subsequent erosion, ore may be found attached to the hillsides at all geological horizons between the Lower Carboniferous and the Lower Silurian. If, in any Arkansas localities, the valleys and ravines showed ore on both sides, indicating a formerly continuous bed, the theory of a supply through fissures from above would be weakened as to those localities. But, so far as I know, such exposures have not yet

been observed. On driving from an ore-outcrop into the hill, hard, barren rock is encountered; and the numerous bore-holes in both hills and valleys have failed to find a bedded ore-body, though, now and then, one may have struck by chance the ore in a still remaining fissure.

I think the diamond drill is better for prospecting in this region than the oil-well churn-drill, because it will bore horizontally as well as vertically, and can therefore be used to discover ore-bearing fissures not exposed by denudation or erosion.

Mr. Garrison points out that my estimate of working-costs in hard ground does not include several items of expense, "such as timbering, pumping, dead-work, repairs, interest and superintendence." Otherwise, he thinks it "about correct, though by no means conservative." I do not know whether he thinks that, in order to be "conservative," it should have been higher or lower. My own idea of conservatism is pretty well satisfied by being "about correct."

As to the cost of timbering, I would say that, in my 22 years' experience in the district, I have never known timbering to be required or attempted in hard ground. There is usually from 100 to 150 ft. of solid limestone overhead; and a few pillars of ore, left standing here and there, are amply sufficient to protect the workings. In soft ground, on the other hand, the cost of timbering is practically counterbalanced by the saving in drilling and blasting.

As to the other items said by Mr. Garrison to have been omitted, he will find in my paper (on p. 402 of this volume) that I have included, per day, $4 for fuel, $2.50 for the engineer, and $4 for the superintendent. The prevailing royalty varies from 7 to 25 per cent., the average being 16 per cent. The percentage of ore in the rock mined ranges from 3 to 10, and averages 6.5 per cent.

The difficulty of getting competent and honest superintendents, to which Mr. Garrison calls attention, doubtless existed during the "boom;" but it is not specially great at present. Certainly a district that can report for a single year an output worth more than $10,000,000 (as Joplin did for 1899), and a total from the beginning of $78,000,000, cannot be lightly condemned as a scene of delusion and deceit.

Wolframite in the Black Hills of South Dakota.

Discussion of the Paper of J. D. Irving (see p. 683).

ALEXANDER FORSYTH, Southport, Me. (communication to the Secretary): In Mr. Irving's able and interesting paper he describes minutely the appearance of the wolframite and its association with the refractory siliceous gold-ore. He also describes this gold-ore, but fails to mention the important pockets of metallic gold found in the Lead City occurrence of it.

I use the term "metallic" in preference to the more usual "free," for it has been found that this gold is not easily amalgamated.

Metallic gold is comparatively rare in the refractory siliceous gold-ores of the Black Hills; hence its occurrence in considerable amounts in the Lead City wolframite district deserves notice.

I possess a beautiful specimen from the Harrison mine. It is a lump of drusy, granular ore, about 6 in. in diameter. The gold is "shot" through it in large and small pin-heads; and in two specially oxidized areas, each about 1½ in. in diameter, it is peppered full.

The famous "Grantz strike," made in the Lead City wolframite locality, produced many beautiful gold specimens.

This district affords an excellent example of the repeated discovery of new mineral values upon old ground. By reason of its proximity to the Homestake vein, this wolframite deposit was inevitably traversed many times by experienced geologists, mineralogists and mining engineers, who evidently must have thrown aside, with no thought of wolframite, the lumps of "black iron" lying about.

I have the admission of an able geologist that, six months before the wolframite was discovered, he visited some of the very mines where it occurred, and passed it by as magnetic iron-ore. At the time of the discovery, the mineral was scattered over the gold-mine dumps in no small quantities, having been culled as worthless out of the gold-ore. It remained for

Mr. Reitz, an amateur mineral collector, and teacher in the Lead City High School, to find what had escaped intelligent prospectors and experts.

The first values extracted from the Lead City wolframite ground came from the "fossil placer"* deposits—sediments bearing gold from ancient lodes, possibly in this case from the ancient Homestake. After the exhaustion of these "fossil placers," the ground was for a time considered as worked out.

Next came the discovery of the refractory or siliceous gold-ore. This was found in a zone above the "fossil placers," and doubtless at first escaped attention by reason of its frequent banded, granular, sandstone-like character, and the non-discovery in it of metallic gold. Later, metallic gold was found in this curiously banded ore. Again, in the same mines, came the discovery of new values in the mineral wolframite, occurring generally above, but quite intimately associated with, the siliceous gold-ore. Probably the unique character of this occurrence of wolframite, as well as its strange granular appearance, caused it to remain so long unnoticed or regarded as magnetic iron-ore.

The moral, "Look carefully for other than the present values," was, curiously enough, heeded still later, in this very district, with extremely successful results. A neighboring mine-owner, prodding around on the surface of his property, looking for wolframite, discovered a new and extremely rich deposit of siliceous ore containing gold in the metallic state. This was the "Grantz strike," mentioned above.

R. W. Raymond, New York City: Mr. Forsyth's remarks concerning the discovery, in old mining ground, of new mineral values, previously overlooked, might be illustrated with many instances in the history of mining; and I would suggest that members of the Institute should contribute to the *Transactions* accounts of such cases of this kind as they have encountered either in their reading or in their practice. There can be no doubt that such a record would be not only extremely interesting, but also highly suggestive and profitable. A few examples which occur to my mind at the moment

---

* See page 686.

may serve as indications of a large harvest of curious and significant facts which could be gathered in this field.

One class of historic events of this character comprises those in which the new value discovered had really not previously existed, but was created by the progress of science and the arts. Under this head falls the utilization of cobalt and nickel, the very names of which indicate that they were at first believed to be worthless and misleading creations of the mischievous underground imps, hostile to mining.

Another class comprises ores which became valuable after the introduction of means of cheap treatment and transportation. For instance, the heavy lead carbonates of California Gulch, at Leadville, Colo., were regarded by the original gold miners as simply a nuisance, because they hindered, by reason of their high specific gravity, the operations of sluicing for gold. I do not think the gulch-miners were for any considerable period really ignorant of the nature of this mineral; but the pieces of it which they encountered in the gulch were solid, and, probably on that account, of low grade in silver, so that they could not be profitably transported over the mountains for metallurgical treatment, or even smelted on the spot for the production of low-grade lead-bullion. It was therefore not a mistake to consider them worthless. But the discovery on Fryer Hill of very rich silver-ores, and the consequent development of Leadville as a great silver-lead camp, bringing, as it did, abundant capital, railroads, smelters, etc., transformed the situation; and the lead carbonates became the basis of an immensely productive metallurgical industry. This industry again reacted upon that of gold-mining; and, under the new and favorable conditions which it established, gold-mines which had been abandoned or disregarded as unprofitable years before, were opened or reopened with great success.

Another similar instance is furnished by the history of the Comstock Lode, the discovery of which was due to the early gold-washings at the foot of Mt. Davidson. This list might be, and I hope that, through the co-operation of the members of the Institute it will be, indefinitely extended.

The Cyanide Assay for Copper.

Discussion of the Paper of Mr. Miller (see p. 653).

EDWARD KELLER, Baltimore, Md. (communication to the Secretary): Mr. Miller's improved method of the cyanide-assay for copper will, without doubt, be much appreciated by assayers and chemists who are engaged at copper mines and works. The writer, as one who, at one time, had much work of that kind to do, entertains no doubt of its practical value.

In enumerating the factors which affect the accuracy of cyanide-titration, Mr. Miller omits to mention *time*. This I have always considered an essential one; *i.e.*, in order to secure accuracy, I have believed it to be necessary to run the cyanide-solution at the same rate of speed in standardizing as in the titration of the samples. I have accomplished this, without the use of a time-keeper and without noticing the volume of the solution, in the following simple manner: In running the cyanide-solution from the burette, the stream was so regulated, by manipulation of the cock, that it retained its continuity for a distance of about one inch below the orifice, and, below that, broke into individual drops. This means that a constant pressure is maintained at the orifice of the burette, so that, during equal intervals of time, equal volumes of the solution pass through. The stream of cyanide-solution was left to flow in the manner indicated until the blue ammoniacal copper-solution began to show a distinct change in color, after which the cyanide was added by drops at regular intervals until the desired end-reaction. When several burettes are used they should have orifices of equal diameter; otherwise, the time-factor must be considered separately for each.

In accordance with Mr. Miller's views, I have always considered the cyanide-method as of very satisfactory accuracy for all copper-assaying in which I did not employ the electrolytic method. It may interest some of my colleagues to know the modified method which I employed some fifteen years ago in making great numbers of copper-estimations on ores and

metallurgical products of the Butte district. The metals to contend with, as deleterious to cyanide-titration, were mainly iron, manganese, and zinc. The mode of operation may be briefly given as follows:

One gramme of ore, or other material, is dissolved in about 5 c.c. of strong nitric acid; the excess of acid is expelled; the residue is boiled with a few c.c. of hydrochloric acid; the solution is diluted to about 100 c.c.; ammonia is added to slight alkalinity; the metals are converted into sulphides by the addition of from 1 to 2 c.c. of ammonium sulphide, the latter (prepared by conducting hydrogen sulphide through strong ammonia until saturation) being kept in stock; the solution is re-acidified with excess of hydrochloric acid; the insoluble sulphides are filtered out and washed; the filter, with residue, properly folded, is placed on top of three or four layers of filter-paper in a scorifier, and incinerated in the red-hot muffle of the assay-furnace; the incinerated residue is dropped into a beaker, dissolved in the desired quantity of acid, and prepared for titration in exactly the same manner as the standard.

The above-described method has the advantage that the copper is practically precipitated instantaneously and completely, and the sulphides of iron, manganese and zinc are very quickly removed by solution in hydrochloric acid. If nickel and cobalt were present in appreciable quantities, this method would not be efficient, because, when once precipitated as sulphides, these metals are but slightly soluble in hydrochloric acid. Arsenic, being present as a volatile sulphide, is probably totally removed by the incineration. Antimony is probably volatilized only in part, but the remainder may be oxidized to insolubility. Should lead and bismuth be present in quantity, it would become necessary to remove them from the incinerated residue by solution in acid, neutralization with ammonia, and precipitation as carbonates with ammonium-carbonate—thus necessitating an extra filtration. The incineration of the sulphides in the muffle-furnace is very convenient and rapid. The placing of three or four layers of filter-paper in the bottom of the scorifier prevents any adhesion of the residue to the scorifier, the simple tilting of which, therefore, allows the residue to fall into a beaker, as soon as the scorifier is taken from the muffle. At the time when I used this method I considered it the

most rapid for the material for which it was devised, and I believe it to be a very practical method to-day. I am no longer in possession of any data of my own to show the accuracy attained in this kind of work. However, Mr. K. W. McComas, my assistant, has lately made a series of titrations with known quantities of copper, to which were added equal quantities of manganese in one series, and zinc in another series—creating conditions far more unfavorable than are generally met in practice. The results are as follows:

Copper taken. Grammes.	Copper found. After separation from zinc. Grammes.	Copper found. Without separation from zinc. Grammes.	Copper found. After separation from manganese. Grammes.
0.0993	0.1050	0.1373	0.1016
0.1986	0.2110	0.2668	0.1992
0.2979	0.3163	0.3563	0.2989
0.3972	0.4223	0.5457	0.3988
0.4965	0.5284	0.7061	0.4962

It will be noticed that when the copper has been separated from the zinc the results are still somewhat too high. This is due to the fact that, when much zinc is present, its sulphide cannot be completely separated from the copper sulphide by hydrochloric acid. The results obtained by the titration of the copper without separation from the zinc show the utter unreliability of the cyanide-method when it is used without that modification.

The Great Oil-Well Near Beaumont, Texas.

Discussion of the Paper of Mr. Lucas (see p. 362).

E. T. Dumble, Houston, Texas (communication to the Secretary): During the field-season of 1890 I had occasion to examine some of the salines of eastern Texas. As the result of my study of them I came to the conclusion that, together with the oil of Hardin county (since extended to Beaumont by the work of Capt. Lucas) and the rock-salt and gypsum-deposits of the coast country, extending southward to the Rio Grande, these were simply a continuation of similar deposits in Louisiana described by Hilgard, Hopkins, and others; and I recommended the sinking of wells wherever they were found.

Prof. Hilgard considers that the deposits in Louisiana are connected with rocks of Cretaceous age, which now occur in a series of ridges having a general northwest-southeast direction, and are, for the most part, entirely covered by deposits of later date. In the illustration published by Dr. Hopkins in his First Annual Report, he seems to represent the Cretaceous as folded along northeast-southwest axes, and in such case the ridges were, supposedly, caused by erosion. Later work in this region by Prof. G. D. Harris indicates that this is the real condition, whether it was so understood earlier or not.

My investigations in the Texas region since that time seem to me to indicate that while the east Texas salines are undoubtedly of like origin with those of Louisiana, the other deposits rather represent a series of similar conditions than any direct connection. Thus, in Brazoria county, at Damon's Mound, which is of late Pliocene age, we find the sulphur on and near the surface; and in Hidalgo, Cameron and other counties there are considerable beds of rock-salt and gypsum which, as nearly as we can determine, also come in connection with deposits of similar age. Consequently the occurrence of sulphur and gypsum with the oil at Beaumont, while it naturally suggests a connection with like deposits in the adjoining State, can hardly be taken as proving conclusively a Cretaceous age for the oil until we have clearer evidence from fossil contents.

Whatever be the origin of the oil or the date of its formation, I think that the present evidence is to the effect that the reservoir from which the Lucas well and others in the Beaumont field obtain their supply, as well as the oil sand which overlies this and has not yet been developed, are in the Lagarto beds of the Pliocene.

The general section of the Texas Neozoic was given by the writer in the *Journal of Geology*, for September, 1894 (vol. ii., pp. 549–567), as follows:

Pleistocene: Coast clays, Equus beds.

Pliocene: Reynosa-Orange sand, Lagarto, Lapara.

Miocene: Oakville.

Eocene: Frio, Fayette, Yegua, Marine, Lignitic, Basal.

The section from Beaumont north to Rockland shows the Coast clays giving place to the Orange sand in the vicinity of Kountz, while the first appearance of the Lagarto clays was ob-

served between Hillister and Woodville. The contact of the Pliocene with the sandstones which we suppose to represent the Oakville in this region is found $2\frac{1}{2}$ miles south of Rockland.

A number of flexures were observed with axes northeast-southwest, corresponding in direction with other flexures and faults previously observed in this area.

At Village Mills, near the contact of the Orange sands and Lagarto, there is a well 1200 ft. deep which passes through shales and sand for its entire depth, and only just reaches the Oakville sandstone. This indicates an average dip of 40 ft. per mile for the top of the Oakville sandstone, and such a dip would eliminate it entirely from the oil-well sections.

The Lapara phase was not positively identified in the section.

The Lagarto, which corresponds with the upper portion of the Navasota beds, as described by Kennedy,* is a series of sands and clays, mixed with lime, which takes the form of concretions, stringers, and thin beds. From the Village Mills well-section we may assume its thickness to be 1000 ft.

The Orange sand and Coast clays have been so often described that it is unnecessary to do so here.

The log of the Lucas well may be generalized as follows:

	Feet.
1. Yellow and blue clays, with sand,	0 to 170
2. Sand and gravel, with some clay and iron concretions,	170 to 352
3. Interbedded shales, clays and sands, with concretions and seams of limestone. Shells and pyrite,	352 to 1160

No. 1 is the Coast clay and No. 2 corresponds with the Orange sand. The details of No. 3, as given by Mr. Lucas in his section, are so like the Lagarto clays in all particulars that there can be little hesitancy in so referring it. Coming up with the oil, we find fragments of crystalline limestone, such as is found in these beds farther west; and even the fossil shells which occur at the bottom of the well are extraneous in origin, as is the case with those found in these beds elsewhere. Nothing in any of the sediments examined, or any of the fossils which I was able to find, indicated an earlier horizon than

* *Fourth Ann. Rept. Geol. Surv. of Texas.*

this. A lot of fragments were sent to Prof. Harris, who writes me that they are simply the same sort of shells that are found on our coast to-day.

While the Coastal plain is now just what its name implies, during Tertiary times it was subjected to oscillations, accompanied by certain phenomena which marked the dying out of vulcanism in this region. West of the Colorado river this resulted in folds and faults trending westward to northwestward, while east of that stream they trend eastward to northeastward. Pliocene, or pre-Pleistocene, erosion, acting in connection with these flexures, left a number of hills and ridges scattered over the coastal strip, which, for the most part, were again covered by the Coastal clays during the Pleistocene submergence. That some of the hills were of considerable height is shown by borings made in suitable places. Spindle Top, on which the Lucas well is located, is apparently one of these; for other wells toward the river show a much greater thickness of Coast clays and Orange sand above the Lagarto clays than is found on the hill itself.

In a region of such flatness of surface as this, it will be very difficult to trace any particular fold or series of domes by any method except actual boring. Consequently we may expect a number of dry holes before any general principle or scheme of occurrence can be outlined.

Gold-Mining in the Transvaal.

Discussion of the Paper of Mr. Hammond (see p. 817).*

Thomas Haight Leggett, London, Eng. (communication to the Secretary): Mr. Hammond has given us a concise yet complete description of the Witwatersrand gold-fields, and the character of the operations which have resulted in their remarkable development.

---

* Secretary's Note.—This contribution was based upon the first pamphlet edition of Mr. Hammond's paper, which had been issued without final revision by the author. In printing it here, some corrections of obvious typographical and statistical errors which do not appear in the revised paper of Mr. Hammond (p. 817) have been omitted. See Mr. Hammond's Postscript, p. 854.—R. W. R.

Of the many matters touched upon in his exhaustive description, there are a few that admit of further elucidation and possible correction. In mentioning these, I follow, for the convenience of the reader, Mr. Hammond's titles.

Referring to the Lydenburg district, while it is quite true that there are some very rich gold-ores in the bedded veins of that section, these are now being worked on a very much larger scale than formerly, and the yield is no longer in ounces, as it used to be. The product for 1898 from four companies, operating 135 stamps, was at the rate of 14.09 dwts. of gold bullion per ton, or about 0.7 oz. of bullion, and not 1.42 oz. gold, as stated. The seven companies operating in the De Kaap gold-fields in 1898 ran 200 stamps (not 180) to produce 89,760 oz. of bullion.

I. Mining Titles in the Transvaal.

The excellent character of the mining law of the Transvaal is worthy of more than passing notice. So clear and well-defined is it, that while every square foot of ground is taken up for a length of nearly 40 miles by a width of from 2 to 3 miles, lawsuits between adjoining properties are practically unknown; and, as a result, the mining-law expert does not exist on the Rand. The lawsuits that have arisen in connection with titles have been chiefly in settlement of disputes as to priority in the "pegging" or location of claims. Encroachments of the mine-workings of one company upon the property of a neighbor have been very rare, and when such do arise they are invariably settled without recourse to litigation.

It is quite true that "certain oppressive features of ground-taxation, monopolies, etc., form no part of the Mining Law proper;" but it is not quite clear just what the "oppressive features of ground-taxation" were that are said to have borne "with special weight on the mining industry." In the Report of Sir David Barbour on "The Finances of the Transvaal and the Orange River Colony," presented to both Houses of Parliament in June, 1901, it is stated (Art. 27):

> "The total receipts from prospectors' and diggers' licenses came to £389,643 in 1898, out of which £178,203 was paid to land-owners, giving a net receipt by the State of £211,440."

As the value of the gold-output of the Transvaal for 1898 was stated by the Johannesburg Chamber of Mines to be £16,044,135, the above tax represents about 1.25 per cent. of this gold output; or, compared with the value of the mineral land upon which it was levied, as it more properly should be, it would represent but a very small fraction of 1 per cent., since that value would exceed a hundred millions sterling.

Sir David Barbour further says (Art. 28):

"The payment on a prospector's license being 5*s.* a month, and on a digger's license 20*s.*, it is to the advantage of the mining companies to hold their claims under prospecting licenses as long as possible; and I have reason to believe that a considerable sum is lost to the State, owing to the mines taking out fewer diggers' licenses than they ought to do. Attention should be paid to this matter, etc." . . . . "On all 'mynpachts' the Government is entitled to claim at any time 2.5 per cent. on the gross production of gold instead of 10*s.* per morgen, *but this provision has not hitherto been enforced.*"

The italics are mine.

Under the head of *Land Tax* (Art. 30), Sir David Barbour says "the direct taxes on land are very light." According to the evidence of this impartial English expert, therefore, it seems that the facts do not warrant the use of the word "oppressive," but quite the contrary. Indeed, it would be more correct to describe the admittedly reasonable ground-taxation as "unequal," inasmuch as the mining licenses bear somewhat heavily on the prospector and small holder of claims, and perhaps too lightly upon the mining companies and rich corporations. The chief monopoly bearing directly upon the mining industry is that of dynamite. According to the State Mining Engineer's reports and other available data, explosives, including fuses and detonators, represent about 9.66 per cent. of the working-costs of the mines. A free market in dynamite would have effected a saving of about 3 per cent. of these working-costs. The reduction of 20*s.* per case, granted October 31, 1901, by virtue of which the old dynamite monopoly is allowed to continue operations, will effect a reduction of working-costs of about 2 per cent.

III. Historical and Commercial Notes.

1. *Financial Conditions.*

In 1898 there were but 77* companies (not 79) "operating

* *Tenth Annual Report of the Chamber of Mines of the S. A. R.*

stamp-batteries" or other crushing-mills; and, of these, one closed down early in the year, having produced (presumably from its clean-up) but 109 oz. of gold, while another produced but 762 oz. from a single crushing of 2000 tons of ore.

These companies produced 4,295,609 oz. of gold bullion, 841.4 fine, equal to 3,614,385 oz. of gold, worth £15,141,376. Forty-one of them distributed the stated amount (£4,847,505) in dividends, being 8.6 per cent. on their market-capitalization, or 26.2 per cent. of their issued capital (£18,512,000) at par.

I am unable to obtain the figures of nominal and market-capitalization of these 77 companies arrived at by Mr. Hammond, namely, £34,000,000 and £92,700,000 respectively, my results being as follows:

		Capitalization.		£4,847,505 Div. pd. in 1898 represents.	
		At par.	At market price.	On par.	On market price.
				Per cent.	Per cent.
77 Producing Cos.	Nom. Cap.	31,018,000	82,555,000	15.6	5.9
	Iss'd Cap.	29,454,000*	79,403,000	16.5	6.1
41 Dividend-paying Cos.	Nom. Cap.	19,178,000	57,948,000	25.3	8.4
	Iss'd Cap.	18,512,000	56,200,000	26.2	8.6

Mr. Hammond's interesting Table II., giving the gold-product of the district, shows at a glance the enormous and rapid development of these gold-fields since 1890, when the cyanide process began to be successfully applied to the tailings. The "ounces" given are gold-bullion; but it is satisfactory to know that this year the Johannesburg Chamber of Mines has decided to report the output in fine gold only, thus falling into line with the rest of the mining world in this particular.

Year.	Percentage of Total Output Paid in Dividends.	
1890,	12.3 per cent.	
1891,	17.8 "	
1892,	20.7 "	
1893,	21.2 "	
1894,	22.1 "	
1895,	28.0 "	("Boom" year.)
1896,	20.8 "	(Reaction.)
1897,	26.1 "	(Normal growth.)
1898,	32.0 "	" "

* Outstanding debentures amount to £2,080,000.

It is interesting to note the increasing ratio that the dividends bear to the total gold produced annually, which works out from Table II. (see preceding page).

So far as the writer is aware, no single gold-mining district in the world, working under such conditions, as to depth and character of deposit, as obtained on the Witwatersrand in 1898, has ever disbursed in dividends 32 per cent., or nearly one-third of its total yield of gold. The enormous increase in the output of gold during '97, '98 and '99 (in the latter year almost as much gold was produced in 9 months as in the full year of '98), amounting to 3 and 4.5 millions sterling in '97 and '98 respectively, was the direct result of the equally great increase of stamping-capacity, which was as follows:

Year.	Total Mining Companies.	Average No. of Mining Cos. for full Year.	Average No. of Stamps.	Increase in No. of Stamps.
1897	69	51	3567	618
1898	77	63.5	4765	1198
1899	79	......	5762	997

These facts speak volumes for the comparatively unhampered and generally healthful condition of the mining industry during these years.

2. *Dividends.*

Under this head, Mr. Hammond's method of arriving at the "Expenses per Ton" of ore crushed seems somewhat drastic. In a sense it is true that all disbursements, excepting those for dividends, are chargeable to "Expenses," yet when one considers that debentures, both interest and principal, are sometimes (the interest almost invariably) paid out of the mine-profits, and that often the cost of machinery or other equipment acquired, of additional development-work accomplished, and, occasionally, of water-rights or other property purchased, is similarly paid, it is evident that these "Expenses" cannot represent the actual working-costs per ton of ore mined and milled.

A table compiled by the writer from the official returns of 65 companies operating in 1898 shows the average yield to

have been 41*s.* 5.1*d.*, the working-costs 25*s.* 1.3*d.*, and the profit 16*s.* 3.8*d.* per ton of ore crushed.

For 1899 these returns are more difficult to obtain; but 42 companies showed, from January to August, inclusive, average working-costs of 25*s.* 2.7*d.* per ton.

3. *Extent of Operations.*

[SECRETARY'S NOTE.—Under this head, Mr. Hammond's revised paper (see p. 825) practically adopts the figures given by Mr. Leggett.—R. W. R.]

4. *Economic Conditions.*

As already pointed out, the number of whites employed on the Rand in '98 was 9476. On page 827, Mr. Hammond says that, "by reason of the rapidly increasing demand for labor and the obstacles interposed by the government, there has been a great deficiency of native labor." In 1896 there were 64,012 natives employed; in 1898 there were 88,627 natives, an increase in 2 years of 24,615, or a rate of influx of 1023 natives per month—certainly not a bad showing. The chief "obstacle interposed" was the bad method of "touting" for natives adopted by the various companies, whereby their "touts," or agents, among the Basutos, Shangans, etc., would bid against each other with the tribal chiefs, increasing the cost of the "boys" tremendously by the time they were landed in Johannesburg.

This has been so universally recognized on the Rand as the chief evil, that the newly reorganized Native Labor Department of the Johannesburg Chamber of Mines has laid down as its cardinal principle the abolition of all "touts," except those employed by itself.

If the chief obstacles had been governmental, and not inherent in the nature of the country and character of the natives, it is fair to assume that Rhodesia would not have suffered for years past from a still more acute form of the labor-trouble to such an extent that the authorities there are to-day earnestly advocating the introduction of Asiatic labor for their mines, mills, railway-construction, etc. On this subject, Mr. Frank

Johnson, writing upon "Rhodesia: Its Present and Future,"* says:

"The periodical, if not constant, want of unskilled labor has, I am sure, seriously retarded the influx of capital. It is useless to disguise the fact that we have not sufficient natives in Rhodesia for our present requirements, even if they could be induced to work, which is impossible. The total native population—carefully estimated by the Native Commissioners—is not more than 449,000, of whom less than 80,000 are adult males between 15 and 60 years of age. The present requirements of the mines are, on an average, 14,000, whilst railway-construction, public works, agriculture and domestic work require at least another 6000. To supply even this amount of labor, it would be necessary for every adult male native to work three months in each year. Roughly, one-half of the adult natives work for an average of six weeks, thus providing only one-quarter of the present requirements. . . . The average native will no more work without some direct (and, I submit, necessary) form of compulsion, than will the average child voluntarily go to school and learn lessons. . . . Therefore, although much useful labor can be obtained in Rhodesia itself, and from neighboring territories, I am firmly convinced that the early and successful development of Rhodesian mines is entirely dependent upon the wholesale introduction—under proper safeguards and restrictions—of Asiatic labor. . . . Scarcity of native labor is no new difficulty in South Africa, and is not confined to Rhodesia. The Colony of Natal, with an area less than one-ninth the size of Southern Rhodesia, has a larger native population than Rhodesia, and yet Natal has had to fall back on Asiatic labor for the development of practically her entire resources."

The foregoing is an excellent picture of the labor-conditions in South Africa, and shows very clearly where the chief obstacles lie, and why they may not be classed as governmental, but rather as inherent in the country. The Transvaal has a larger source of supply to draw from, in the Portuguese or East Coast territories; and, up to the present time, so far as the writer is aware, no attempt has been made to import Asiatic labor. Whether it may not come to this later, is another question.

On page 828, Mr. Hammond says that "the white and the native labor represent about 30 per cent. each" of the working-costs. From the annual reports of the former State Mining Engineer of the S. A. R.; from mines with which I am connected; and from other reliable data in my possession, I find that white labor represents about 31.25, and native labor (including food) about 29.75, or, together, 61 per cent. of the working-costs.

In this connection, the following table which I have com-

* In a paper read before the *Royal Colonial Institute*, Nov. 12, 1901.

piled from the State Mining Engineer's reports for several years, and from other reliable sources, may be of interest. The figures are, however, not absolutely up to date, since it has been impossible, thus far, to obtain similar data for the operations of the year immediately preceding the war.*

	Percentage of Working-Costs.
White labor,	31.22
Native labor (including food),	29.83
Explosives (dynamite, fuse, caps),	9.70
Coal,	9.07
Chemicals (cyanide, etc.),	3.22
Tools, steel, shoes, dies, etc.,	3.29
Mining timbers, lumber,	4.05
Candles and lighting,	1.38
Sundries,	8.24
	100.00

Regarding railway rates, it is to be regretted that Mr. Hammond quotes those of so long ago as 1896 and the early part of 1897.

According to the legal adviser of the Johannesburg Chamber of Commerce,† the following were the correct comparative rates in October, 1899:

Via.	Per Ton per Mile.		
	Normal.	Intermediate.	Rough Goods.
Cape	2.34*d.*	1.7*d.*	1.6*d.*
Orange Free State	2.34*d.*	1.7*d.*	1.6*d.*
Natal	3.24*d.*	2.28*d.*	2.21*d.*
Netherlands Line, to:			
Cape and Orange Free State	7.3*d.*	6.15*d.*	3.8*d.*
Natal	4.74*d.*	3.8*d.*	2.8*d.*

The average local rates for normal goods on the various systems for 150 miles were stated by the same authority to be as follows:

Netherlands railway,	6*d.*	per ton per mile.
Cape "	4.3*d.*	" "
Natal "	4*d.*	" "

* This table has been adopted by Mr. Hammond (see p. 828).

† Bleloch, *The New South Africa*, 1901, p. 260. The tables given on this authority have been adopted by Mr. Hammond (see p. 829).

Mr. Hammond (p. 829) puts the coal-rate at 3*d.* per ton per mile. This is 50 per cent. too high; the rate being 2.03*d.*, according to the authority just quoted, who says, "the coal-rate on the Cape and Natal railways is ½*d.* per ton per mile." These, however, are all long hauls.

"On the Netherlands railway, the coal-rate varies according to distance, and is on the zone system, which works out for a long distance, say Middelburg to Middle Vaal River, 173 miles, at 0.83*d.* per ton per mile, but on the line from Springs to Johannesburg, which would represent the bulk of the coal-traffic, the rate is 2.03*d.*"

The average coal-haul to the Rand is 25½ miles. To-day, in England, on the Northeastern railway, the average rate per ton-mile is 1.24*d.* for an average haul of 22¼ miles.*

While not defending the very high charges of the Netherlands railway, I believe it is characteristic of all new railways into mining camps to charge high freight-rates. It is evident that substantial reductions had been made since the time of the rates quoted by Mr. Hammond. According to one authority, these reductions were equivalent, in the aggregate, to an annual saving of £200,000.

V. Genesis of the Auriferous Banket.

It is difficult to reconcile all of the phenomena in connection with the occurrence of gold in these "banket-reefs," so as to make them fit any one of the theories of origin that have thus far been propounded; and this difficulty was ably set forth by Prof. L. de Launay in his excellent paper, presented June, 1896, to the *Federated Institution of Mining Engineers*, and entitled "Geological Description of the Gold-Mines of the Transvaal (Witwatersrand, Heidelberg and Klerksdorp Districts)." I agree, however, with Mr. Hammond that the theory of subsequent infiltration or impregnation best accords with the majority of the observed facts.

VII. Milling.

In 1898, out of 75 stamp-mills in operation (the two others being dry-crushing plants with rolls), 41, or 54.66 per cent., contained 60 stamps or less, while in 1899, out of 77 stamp-

* *The Statist*, December 14, 1901.

mills in operation, 43, or 55.8 per cent., had but 60 stamps or less. It is natural that more than half the mills should be of this smaller type, since the mining area of the "outcrop-companies," which are the chief producers to-day, is, as Mr. Hammond points out, much smaller than that of the "deep-levels." Hence, 60-stamp mills can hardly yet be spoken of as "rare on the Rand."

In 1898 and 1899 there were but 5 stamp-mills of 200 or more stamps in operation. Unquestionably, the tendency is towards large milling-capacities of 200 stamps, and even more; but as this is dependent upon the mining area of the company concerned, such mills are chiefly confined to the deep-level properties, in the formation of which it is customary to combine, at the outset, a sufficient number of claims to permit the erection of large mills.

The extraction of gold by amalgamation on copper plates rarely falls as low as "50 to 60 per cent." In 1898 it was 66, and in 1899 65 per cent. of the total output.

VIII. Treatment by the Cyanide Process.

With reference to concentration by hydraulic classifiers, Mr. Hammond says (p. 848):

> "About 10 per cent. of the mill-pulp recovered in this way consists of pyrites with coarse sand, a concentration of 10 to 1 being obtained."

The amount of concentrates produced by the *Spitzlutten* varies greatly at the different mines; for instance, at the Treasury it is 3.5; at the Consolidated Main Reef, 11.3; and at the Nourse Deep, 17.9 per cent.; while, according to Mr. Hennen Jennings, the average of seven Rand Mines' Subsidiaries for 1898 was 11.3 per cent. of concentrates from this source.

The chief advantage of the double treatment of the tailings, which is now universally adopted on the Rand, lies not so much in "saturating the sands with the solution" as in their aëration after such saturation, obtained by their discharge (usually by shoveling) from the upper into the lower tank, thereby securing a more rapid and complete solution of the gold in the subsequent treatment.

IX. The Future of the Witwatersrand Gold-Fields.

Under this head, Mr. Hammond says (p. 851) that, "within

one year after the resumption of mining operations,* an output of gold at the rate of over 20 millions sterling annually may be reasonably estimated."

Mining operations were resumed in May, 1901. The output for November, 1901, was 39,075 oz. of fine gold from 550 stamps, or one-tenth the output of the Rand during the month of July and the month of August, 1899, from 5950 stamps. Permission has just been granted to drop 100 additional stamps every week, at which rate it would take a little more than one year, or till January, 1903, to get all the stamps into operation that were crushing in 1899; and while it is reasonable to expect this rate to increase substantially as the months go by, it must also be remembered that many thousands of native laborers have yet to be secured, and that much difficulty has been experienced in this direction, largely owing to the unsettled condition of the outlying country.

In view of these facts, it is fair to assume that Mr. Hammond anticipates the estimated output of gold to be reached "within one year after the resumption of mining operations" *upon the scale existing immediately prior to the war*, as it is manifestly impossible for anything like even the old rate of product to be established by next May.

After speaking with well-founded confidence of the possibilities of working to the depth of 6000 ft., and ultimately, perhaps, to 8000 ft., Mr. Hammond remarks that, in his opinion, profitable operations upon a large scale will be carried on upon the Rand for a period of less, rather than more, than 25 years.

To one conversant with the Witwatersrand mines, these two opinions seem greatly at variance with one another.

Of the second row of deep-level mines there is at present but a single one that has reached the stage of crushing ore, namely, the Robinson Deep. The average depth of shaft on these mines is 2611 ft.,† and several of them—as, for instance, the Knight Central, Ltd., and the Jupiter—have lives of 30 years or more, when equipped with mills of 200 stamps.

While it is true that the lives of these unusually large mines

* Mr. Hammond has added here the qualifying clause suggested by Mr. Leggett, "upon the scale existing immediately prior to the war."

† "Deep-Level Shafts on the Witwatersrand," etc., *Trans.*, xxx., 947.

may be reduced in the future by the disposal of a portion of their claims to neighboring companies, it is fairly certain that this second row of deep-levels alone will endure for more rather than less than 25 years; for it must be remembered that the lives of mines upon the Rand are estimated upon a very conservative basis; and of the few mines that have thus far been exhausted, all have lasted for several years beyond the calculated time of extinction, while others, nearing that point, are now known to have had their lives considerably underestimated.

It is the constancy of the error in one direction to which I wish to call attention.

Again, the development and equipment alone of mines requiring shafts from 4000 to 5000 ft. in depth will take from 6 to 8 years, even at the rapid rate at which such work is accomplished in this district.

In view of the foregoing observations, and of the large area of mining-ground still to be exploited between the present second row of deep-level mines and the possible ultimate depths of 6000 to 8000 ft., I am forced to the conclusion that the duration of operations on a large scale upon the Rand has been much under-estimated in placing it at rather less than 25 years.

Finally, Mr. Hammond estimates a reduction in working-costs of 6*s.* per ton, as the result of "economic reforms due to the establishment of a better government." As I have already shown, the working-costs on the Rand before the war were about 25*s.* per ton, hence a reduction of 6*s.* means a decrease of these costs by nearly 25 per cent.—certainly a very remarkable saving, as the result of a change in government. It is the history of all large mining districts to cheapen costs as their age and productivity increase. Such a reduction is a natural and inevitable one, but it does not enter into the present question; in fact, it is definitely excluded from Mr. Hammond's prophecy.

I confess I cannot agree that such a net decrease will be effected by the causes Mr. Hammond cites, or indeed by any others in the near future. It is certain that some reductions will be obtained through governmental economic reforms, and that other and much more substantial ones will be effected

through other means; but it is equally certain that the change in government, and allied causes, will result in increased charges upon, and therefore increased working-costs for, the mines; and it is not yet known to what extent the latter loss will offset the former gain. Certain of these charges are already known, while others are partially foreshadowed; and one may rest assured that their effect will be seriously appreciable.

An estimate to-day of the probable saving in working-expenses on the Rand in the near future is an important matter, far-reaching in its effects. The mere statement that this reduction will amount to 6*s*. per ton through the causes named, carries no conviction; and I feel that I must call upon Mr. Hammond to give chapter and verse for the faith that is in him.

Postscript.*

(July 5, 1902.)

From the revised edition of Mr. Hammond's paper, which has just reached me, I note that there now remain but two main points of difference between us, namely, as to the life of the Witwatersrand, estimated by him at less than 25 years, and as to a reduction in working-costs of six shillings per ton, which Mr. Hammond counts upon as the result of "economic reforms" due to "the establishment of a better government," and from "the economy resulting from increased efficiency of labor due to the betterment of living conditions."

With regard to the life of the Witwatersrand, Mr. Hammond does not deny the fact, pointed out in my previous discussion, that the second row of deep-levels alone will last for fully the length of time he assigns to profitable operations on a large scale for the entire district.

But the first row of deep-level mines will also greatly outlast this period. Mr. George E. Webber, for six years past General Manager of the Rand Mines, Ltd., writes me as follows:

"The Rand Mines, Ltd., embraces at the present time nine deep-level milling companies, operating 1140 stamps, and adjoining outcrop companies on the south, thus constituting the first row of deep-level mines. They are opened with vertical shafts ranging from 560 ft. to 1497 ft. in depth.

* Secretary's Note.—Received since the printing of the foregoing contribution.—R. W. R.

"The life of these mines, based on the present stamping-power and the amount of reef-extraction which it is calculated will be made in the three gold-bearing reefs combined, is estimated to approximate, in the aggregate, an average of 35½ years."

The average depth of the vertical shafts on the second row of deep-level mines is 2611 ft. Hence, if the large area of reef-bearing ground lying between 4000 and 6000 ft. of vertical depth be entirely neglected, it is evident that the "duration of profitable operations on a large scale in the district" is sure to exceed greatly Mr. Hammond's estimate of "less than 25 years."

Dr. Frederick H. Hatch and the writer have recently prepared for the Institution of Mining and Metallurgy, London, a paper entitled "An Estimate of the Gold Production and Life of the Main Reef Series, Witwatersrand, down to 6000 Feet." Without forestalling its publication, I may mention that working to the given depth insures a life of 42 years. This estimate, however, makes no allowance for a gradual decrease of production, which would probably add at least 5 or 6 years; and it assumes, perhaps, a more rapid development of the deep-level ground than may actually take place.

It is not asserted by the authors that mining will be carried to a depth of 6000 ft. in all parts of the Rand. No one can say to-day what ultimate depth will be reached, because so many factors, at present indeterminate, affect the vital question of the profits to be derived from very deep mining. It is simply pointed out that the physical conditions, so far as known, favor, and technical considerations do not preclude, mining at these greater depths.

With reference to Mr. Hammond's estimated saving in working-costs of six shillings per ton, I have already pointed out that "the change in Government and allied causes will result in increased charges upon and therefore increased working-costs for the mines"—having in mind at the time, among other things, Sir David Barbour's proposed increase of the Government tax upon gold-mining companies' profits from 5 per cent. (as under the old Government) to 10 per cent. This is now an accomplished fact; and this tax alone is estimated to yield £500,000 per annum.

The recently issued budget of the new Transvaal govern-

ment shows that there will be no cancellation of the dynamite monopoly at present, and no further reduction in the price; and it gives no indication of any early reduction in railway-rates, which are the same as before the war. Customs duties also remain the same; but a reduction of these is promised, though its extent is not stated.

The Chancellor of the Exchequer recently stated in the House of Commons that a bonded debt of £30,000,000 would be placed upon the Transvaal (heretofore practically free from debt), and indicated that, as the revenues of the country increased, it would be able to carry a greater proportion of the war debt.

The cost of maintaining the South African Constabulary is estimated at several millions sterling per year; and the greater proportion of this must eventually be borne by the Transvaal, and not by the much poorer Orange River Colony.

The inefficiency of white labor on the Witwatersrand is not due to the "living conditions," but to the use of kaffir labor. Every mechanic wants, and generally gets, a "boy" to carry his tools for him; and, underground, most of the hard work is done by natives, who are even learning to run air-drills while the white men do the "bossing." This is a condition always met with where white and black labor come in contact with one another; and no "betterment of living conditions" can possibly affect it. It is, in fact, a governing condition of the country, to last as long as kaffir labor is used, *i.e.*, practically always. The betterment of living conditions will be a slow process, as will also be any reduction of wages. A saving of £1000 per year in, let us say, a manager's salary, is of relatively minute importance where working-costs are so huge as on the Rand. For instance, at the Geldenhuis Deep for 1898 the total working-costs amounted to £289,442, although only 20*s.* 4*d.* per ton.

For the foregoing reasons it is clear that a reduction of working-costs amounting to six shillings per ton will not be attained in the reasonably near future. Yet that Mr. Hammond alludes to the near future is evidenced not only by the context, but by the fact that his calculation of the resultant saving per annum is based upon the tonnage crushed in 1898, and not upon the probable tonnage of, say, 1910.

I can but feel complimented by the inclusion of so many of my figures in the revised edition of Mr. Hammond's paper, and by his kindly recognition of the spirit in which they were tendered. Honest differences of opinion will always arise. I regret only that Mr. Hammond contents himself with a bald statement of his views, and does not fortify them with such facts and figures as would carry a greater degree of conviction to his readers.

INDEX.

[NOTE.—In this Index the names of the authors are printed in small capitals and the titles of papers in italics. Casual references, giving but little information, are usually indicated by bracketed page-numbers.]

POSTSCRIPT.

Errata in Vol. XXX.

Page 711, footnote: the second analysis should read 41.37; 57.27; 0.58;—instead of 41.56; 57.79; 0.65.

Page 713, second footnote: instead of "petzite," read "a yellow telluride (kremerite or calaverite)."

These corrections were received from Mr. E. S. Simpson, Perth, West Australia, long after the publication of the paper to which they refer.

R. W. R.